ALLIS-CHALMERS Electrical REVIEW

2ND QUARTER 1960

ALLIS-CHALMERS
Electrical REVIEW

THE COVER

EXPERIMENTAL MAGNET SECTION—one of four recently shipped to the Midwestern Universities Research Association (MURA), Madison, Wis. The four magnet sections, which have already been assembled into two complete magnets, will be used to confirm theoretical calculations concerning the density and shape of its magnetic field. The magnet coils, designed to operate at 200 volts and 70 amperes, will produce a field varying from 500 to 17,000 gauss over the face of the magnet. For a more complete report on developments at MURA, see page 26.

Allis-Chalmers Staff Photo by Michael Durante

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DC POWER TRANSMISSION FOR U.S.?

by **W. E. GUTZWILLER**
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Recent dc transmission developments in Sweden, England, France and Russia have revived the question of dc transmission for U.S.

EACH NEW DEVELOPMENT in electric power conversion in the past thirty years has caused transmission engineers to reconsider the economics of dc transmission. The development of thyratron tubes, single-anode grid controlled mercury arc rectifiers and modern semiconductor rectifiers have each caused a reawakening of this interest.

The economies of the dc system are primarily in the better utilization of the line, resulting in a much lower line cost per kw transmitted. At the present time, the cost of the terminal equipment of a dc transmission system is higher and the reliability is less than for ac. Studies show that a point-to-point overhead dc transmission line must be at least 400 to 500 miles long, in order to have the cost savings in the line pay for the higher terminal costs.

Operations in U.S. and abroad are compared

Some 15 years ago long distance overhead dc transmission looked promising. Today, however, with the great progress made in high voltage ac transmission, the chances for overhead dc transmission have greatly diminished. Another reason favoring ac transmission is that our sources of power — coal, oil, water, and nuclear — are or will usually be located within reasonable distances, that is, 150 to 200 miles, from our large load centers. Hence overhead ac transmission from power source to user is both practical and economical. There are some exceptions, however, in a few long distance system tie lines.

Many European countries have more suitable conditions for dc transmission than we have. Sweden and Russia recently have built their first experimental dc transmission systems using mercury arc rectifier-inverters. The Swedish transmission uses a single conductor submarine cable with return through the sea, while the Russian experimental line is part overhead, part underground cable. As a result of experience gained with these first, medium capacity lines, larger commercial dc systems are now being constructed.

The first one is the Stalingrad-Donbas transmission system, the first phase of which is expected to go into service the latter part of this year. This system is rated 750,000 kw at 400 kv and is 310 miles long. The mercury arc rectifier-inverter tubes are of the excitron type and are each rated 300 amperes, 130 kv.

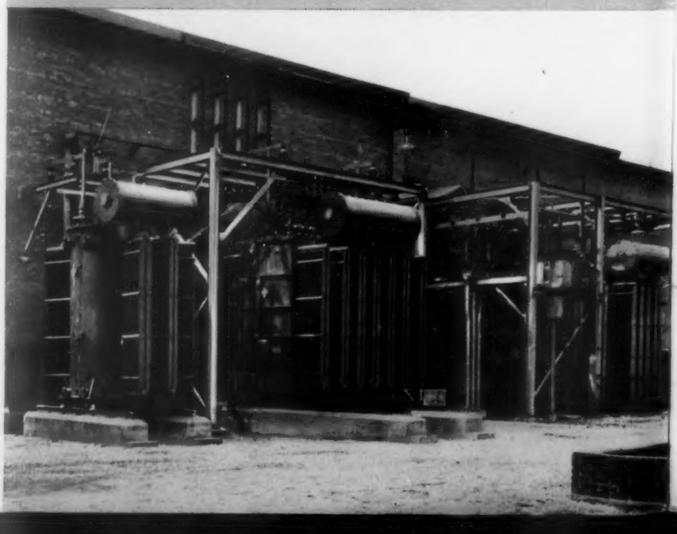
The second commercial size system is the submarine dc transmission across the English Channel, which is due to go into service the latter part of this year. It is designed for 160,000 kw, 200 kv with a length of 38 miles. Other foreign projects which are being seriously considered are a transmission from Italy to Yugoslavia and a large project in New Zealand, both projects using submarine cables.

Know-how is available in U.S.A.

The first experimental dc transmission in this country was built in New York State in 1936. Initially, high voltage thyratron rectifying and inverting tubes were used which were later replaced by mercury arc tubes. The transmission was designed for 5000 kw, 30 kv. The operation was discontinued in 1945.

Two electronic frequency changers utilizing mercury arc rectifier and inverter tubes have been operating for some 15 years. Both installations are rated approximately 20,000 kw — one being in the Edgar Thompson Works, Pittsburgh, and the other in the Gary Sheet & Tin Mill of the United States Steel Corporation. They form flexible ties between the 25 cycle steel mill generating systems and the

INSTALLED AT A MIDWEST steel mill, this 60-cycle transformer bank feeds a 20,000-kw electronic frequency changer.



60 cycle utility system and are designed for transmitting power in both directions. The rectifiers are used for load demand control, while the inverter tubes are used only for power inversion.

These frequency changer installations have all the essential components of a complete dc transmission system combined with frequency changing except that because of local conditions, the transmission voltage is only a few thousand volts dc and the transmission distance is only about 30 feet. The main duty of these installations is to prevent high load peaks of the steel mills from being thrown on the 60 cycle systems which operate mainly on purchased power. Considerable savings are thus made in power demand charges. These installations have operated very successfully under severe industrial duty.

For a present day dc transmission installation, tubes of much greater rectifying and inverting capabilities are needed than are available. The latest foreign installations indicate that it should not be too difficult to design these tube ratings from available ratings. Should a market develop, such a design program could be carried out in a reasonable time and at a reasonable cost.

Silicon rectifiers possible

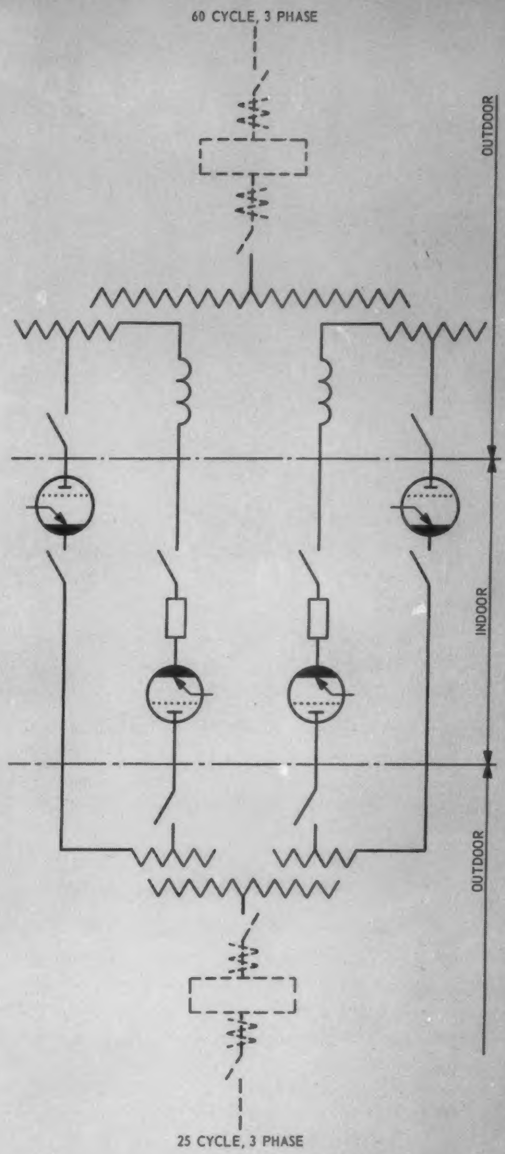
With the advent of the silicon semiconductor rectifier, new possibilities of simplifying the dc terminal equipment and of reducing its costs are now in sight. By cascading silicon diodes of relatively medium voltage ratings, the high dc voltages required for dc transmission can be obtained.

Recent development of the controlled silicon rectifier, which is already commercially available in ratings of 100 amperes and 500 peak inverse volts, means that this device may soon replace the mercury arc inverter tubes at medium voltage. The possibility also exists that the high voltage series stacks of silicon rectifiers may be physically built into the rectifier or inverter transformer, thus eliminating the secondary bushings and using a common cooling system for transformer and rectifier.

The controlled silicon inverter, because of its faster deionization time, should require smaller firing advance angles than mercury arc tubes and hence would require less kilovars.

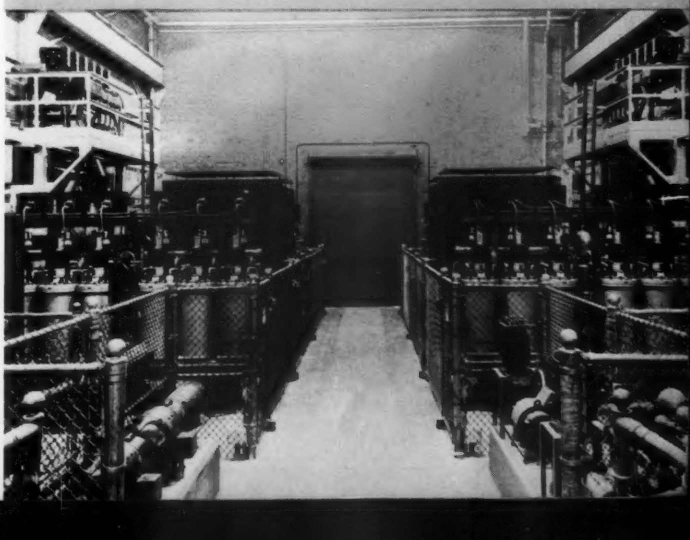
Dc cable transmission going into operation

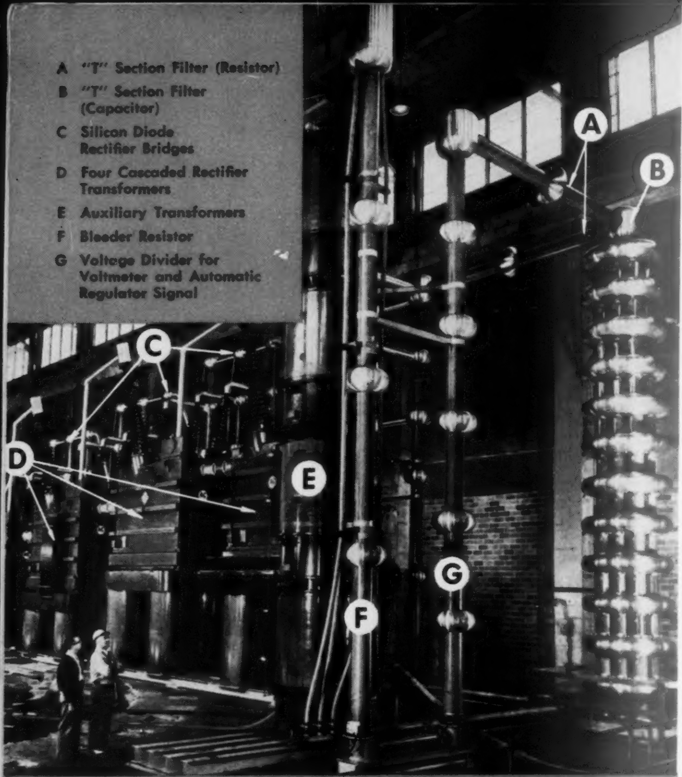
The English Channel system, also the most recent Italy-Yugoslavia and the New Zealand projects, are all medium distance submarine cable transmissions, where the advantages of direct current are most evident. While we do not have geographical conditions in this country where large blocks of power must be transmitted by submarine cables, we definitely face serious problems in transmitting large blocks of power to congested metropolitan areas. Because overhead transmission is not feasible, underground cables must be used. However, to transmit large blocks of ac



ESSENTIAL COMPONENTS OF an electronic frequency changer system are the same as would be used for the terminal equipment of a dc transmission system.

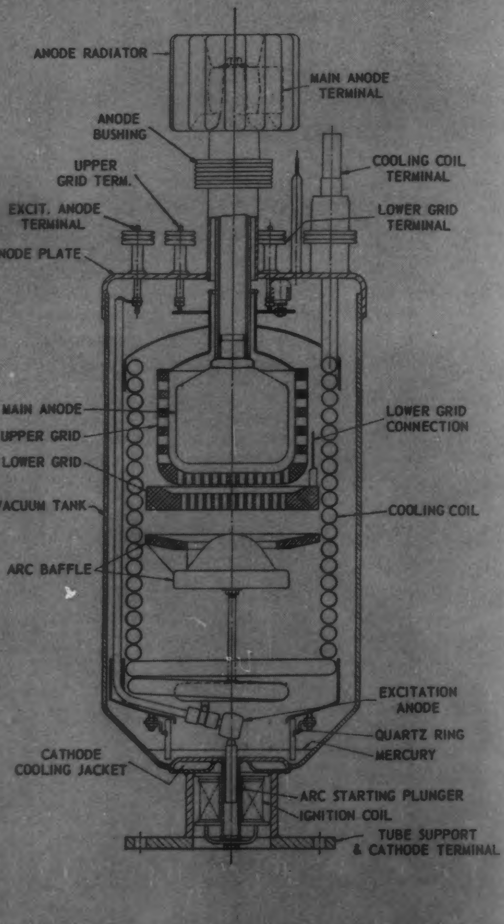
INTERIOR OF FREQUENCY changer installation shows rectifier tubes and control compartments. Unit ties the mill generating system and utility system.





SPECIAL HIGH VOLTAGE dc silicon diode rectifier substation at Oak Ridge, Tenn. This 600-kw, 600-kv power supply is used to further fusion studies.

CROSS SECTION THROUGH a high power sealed excitron type tube for inverter service. Tube has same general construction as pump type.



power by cable over a distance of 15 to 30 miles, it is necessary to resort to very high ac voltages to hold voltage drop within economical limits. At these high ac voltages, the dielectric losses and cable charging currents are greatly increased. For instance, a 345 kv cable carrying no effective load will be thermally overloaded by the charging current alone if its length exceeds 25 miles.

Conditions for cable transmission are greatly improved with dc. Resistance rather than capacitance determines the distribution of dielectric stresses. Cable insulation can be stressed up to as much as three times that of the ac rms voltage.

In many metropolitan areas there is already a shortage of cable duct space in streets. This shortage could well become the most important consideration in favor of cable transmission and may favor direct current.

Fuel cells and other sources may have effect

Recent progress made in the development of new sources of electric power, such as the fuel cell and the magnetohydrodynamic generator, means new emphasis will be placed on devices to change large blocks of dc power at medium voltages into ac power of conventional voltages and frequencies. It is very likely that both the mercury arc inverter tube and the controlled silicon rectifier may be applied to these systems. Their choice will be a matter of economy.

While dc power transmission is not generally economical at present, operating conditions are changing and they may change in favor of dc transmission in certain areas of the United States. New techniques of producing dc power may, in the near future, cause a change in these economics.

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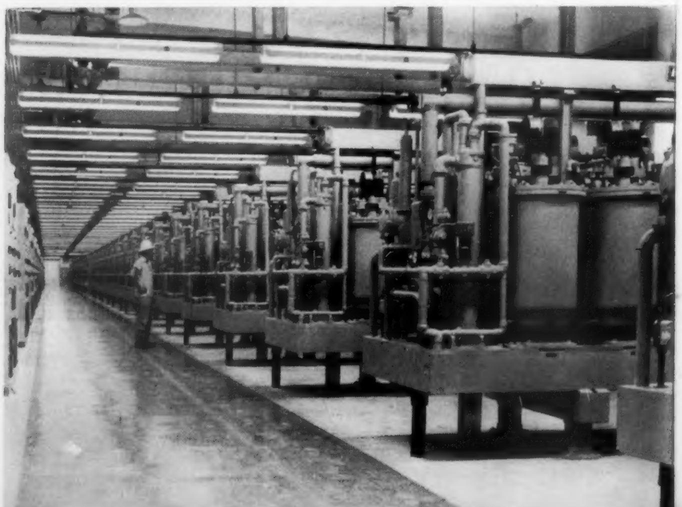
2. "Work Done in the Soviet Union on High-Voltage Long-Distance DC Power Transmission," A. M. Nekrasov and A. V. Posse. AIEE Transactions Paper, Winter General Meeting, New York, N. Y., February 1-6, 1959.

RECENT industrial rectifier installation supplies three 80,000-ampere, 850 volt dc potlines in aluminum plant. A total of 48 rectifiers are required. Each rectifier has 12 exitron tubes rated 5000 amperes.



CROSSED-FIELD ACCELERATION ADVANCES WIND TUNNEL TECHNOLOGY

by **RICHARD B. STANTON**
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M H D Research, Inc.
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Continuous testing at high velocities in larger test areas is now possible with new-type plasma accelerator.

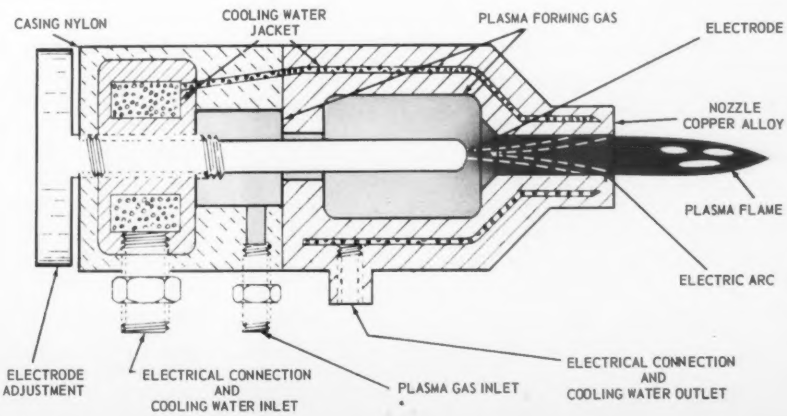
DEVELOPMENT OF BALLISTIC MISSILES and artificial satellites places a premium on re-entry simulation and data. The aerodynamics of such vehicles and the resistance of their materials to very high heating rates must be investigated under controlled laboratory conditions.

Present developments of electric arc plasmas have been in the direction of simulating ballistic missile re-entry environment with some thought to manned re-entry simulation. These developments indicate the need for designing versatile facilities capable of simulating environments for examining all types of thermal protection schemes, materials and reactions associated with extremely high or low speed re-entry.

Recent developments have gone a step beyond the conventional techniques used in the generation of plasma and hypersonic velocities by utilizing an accelerator connected in tandem to the plasma generator. The new accelerator technique permits continuous testing at substantially increased velocities, larger cross sections, and results in much less contamination than conventional methods. Although not yet fully explored, it appears the new technique will offer the aircraft and missile industries greater control flexibility, and may open the door to computer programmed missile re-entry simulation.

Uses conventional plasma generator

Plasma generators similar to the unit shown in Figure 1 have been commercially available for several years. Basically, the generator consists of two electrodes, one electrode being a water-cooled containment vessel with an orifice through which the gas may pass around the other electrode. Gas, in passing through the arc struck between electrodes, is rapidly heated to extremely high temperatures, and expands outward through the orifice at high velocities. This type of generator may be operated with either a carbon or tungsten cathode. The cathode operates at high temperatures as a thermionic emitter of electrons.



PLASMA GENERATOR adds energy to the incoming gas, causing it to ionize. Gas is heated by forcing it through the electric arc struck between the tungsten cathode and the cylindrical copper anode. During operation, the generator is cooled by high velocity water flow. **(FIG. 1)**
Courtesy Thermal Dynamics Corp.

HYPERSONIC WIND TUNNEL schematic shows the principle underlying the acceleration of plasma. Because the gas is ionized, it acts as a conductor. When current is passed through the conductor perpendicular to a magnetic field, the conductor (plasma) is accelerated downstream. **(FIGURE 2)**

The anode operation is limited principally by the aerodynamic heating and the rate at which heat can be removed from the surface by the coolant system. The quantitative limitation tends to be the maximum enthalpy that can be imparted to the air. This is about 12,000 Btu per pound of air.

As one of the most commonly used materials for the cathode, carbon has the ability to withstand very high temperatures for brief periods. As a result, carbon can be used for very high power densities — even in the megawatt region. However, when used at high power densities, carbon will ablate or vaporize, thus contaminating the plasma. It also tends to pull off from the main mass in agglomerate pieces.

Tungsten, on the other hand, cannot stand such high current densities and gas velocities. Tungsten liquifies in a little pool at the point of arc attachment. At higher velocities, this pool of tungsten is literally sucked into the stream and results in contamination.

Of the two, the tungsten cathode will provide less contamination to the plasma than carbon; however, carbon may run at higher power densities. It is obvious that either of the possibilities is satisfactory only when used within their limitations. In aerodynamic applications, contamination greater than 1 percent cannot be tolerated because (1) the contaminant impinges on the sample, causing erosion, and (2) there is a possibility of chemical reaction between the specimen and contaminant.

In order to simulate accurately the thermodynamic conditions encountered on re-entry of a high speed missile into the atmosphere, it is desirable to produce gas stream velocities in a test facility on the same order as missile velocities, that is, 15,000 to 30,000 ft/sec. With present plasma jet technology, it is possible to achieve experimentally a velocity of about 12,000 ft/sec by means of aerodynamic expansion through a de Laval nozzle. This limit is basically tied to material limitations at the throat of the nozzle. For clean operation with air, the power density at the throat is limited to about 12 kw/mm^2. Carbon electrode plasma jets are capable of operating up to approximately 18 kw/mm^2 but in doing so will add as much as 25 percent contamination to the flow. However, this increase in throat power density *does not* lead to a substantial increase in flow velocity.

Includes de Laval nozzle

Following the plasma generator is the plenum chamber and the de Laval nozzle, as shown in Figure 2. In the plenum chamber, plasma is thoroughly mixed and, if necessary, additional gases may be added to give the desired conditions at the test section. In some cases, the additives may be corrosive gases that could not be passed through the plasma generator — for example, when simulating rocket exhaust.

On passing through the de Laval nozzle, the gases are accelerated to supersonic velocities. By decreasing the diameter of the throat, it is possible to accelerate the gases to higher velocities. However, as the throat of the nozzle becomes smaller, it is more susceptible to the effects of erosion. When the throat is made small in an effort to achieve higher velocities, it increases the probability that a contaminating particle torn from the electrode will become lodged in the throat.

New plasma accelerator developed

Since the plasma generator has operating limitations, a system has been developed to increase the enthalpy input into a continuous plasma jet, and also increase control flexibility. The accelerator shown in Figure 2 utilizes the j x B Lorentz body force to further accelerate the already supersonic plasma jet. By the application of the tandem-connected accelerator, it is possible to double the enthalpy of the plasma jet, with little or no increase in the contamination of the jet.

Basically, the physical principle underlying the acceleration is the same as the driving force which rotates an electric motor. Any electric conductor carrying current in the presence of a magnetic field experiences a force. In this accelerator, metal electrodes inserted into the plasma flow serve as "brushes" for a current discharge, I, across the gas flow perpendicular to the stream velocity, v. A magnetic field, generated by an iron core electromagnet, is applied transverse to both v and I so that the motor force is in a direction to accelerate the gas along the channel.

To substantiate the theory underlying the crossed-field accelerator, laboratory investigations were conducted on a prototype model, shown in Figure 3. The results obtained from this facility have been used in the design of a large-scale facility.

Confines plasma within tube

The new approach to the source and accelerator sections differs somewhat from conventional methods. In the experimental facility, many hours of running time have been accumulated with 10, 15 and 20-minute runs within a confined transparent tube assembly.

The accelerator confining tube assembly is water cooled by a slow rate of water flow, and during operation the hand may be held against the side of the assembly with no noticeable heating effect. On the inside of the tube, however, temperatures on the order of 15,000 F are present.

Different cooling systems are employed for each section of the apparatus. The initial plasma generating head assembly uses a high pressure, high flow rate cooling system to obtain high velocity internal skin cooling on the cathode and anode surfaces. The de Laval nozzle utilizes the same high pressure, high flow rate system and under these cooling conditions there has been no measurable erosion. The accelerator section, as mentioned above, is cooled by slow flow rates, and the expansion section following the accelerator is cooled by fast flow. Each cooling system may be individually controlled to obtain optimum test conditions and efficiency.

Since relatively long testing periods — 15 to 20 minutes — are often desirable for aerodynamic studies, a continuous power supply is required. Using rectifiers as the dc power supply, it is possible to operate the new plasma accelerator system continuously, dependent only on the lifetime of the electrodes.

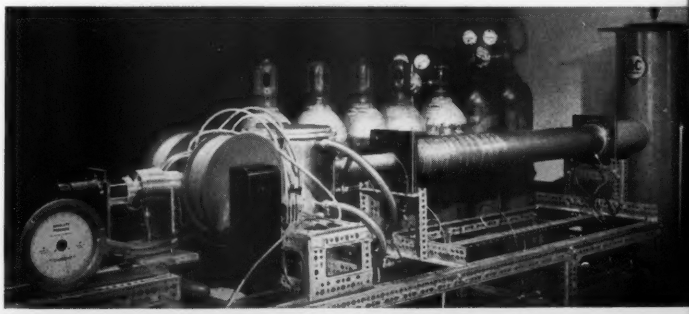
The rest of the system is set up with completely interchangeable chamber assemblies so that, if necessary, the arc head could be mounted directly in the working test section.

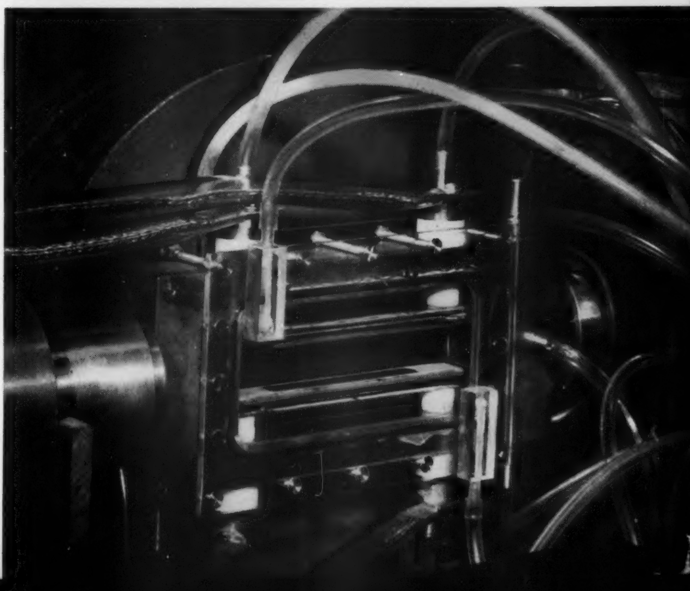
Allows flexible operation

In operation, the system can be used to produce many different conditions. The primary control of the system is in the plasma generator units. Specific enthalpy ranges and specific temperatures can be established by means of the power/gas ratio. Secondary control is in the crossed-field accelerator. The energy input can be controlled by varying the magnetic or electric field. Electric field control provides the most flexible control since it can be varied over a wider range.

These operations could be manually preset, semi-automatic or computer programmed for simulating a specific re-entry curve or whatever type of conditions are to be expected. The acceleration during this period of time would probably be at a preset value, with the exception that if the stream conditions change drastically, a corresponding change would be required in both the *E* field and the magnetic field. These changes, however, could be tied into an automatic or semi-automatic program or computer-type program.

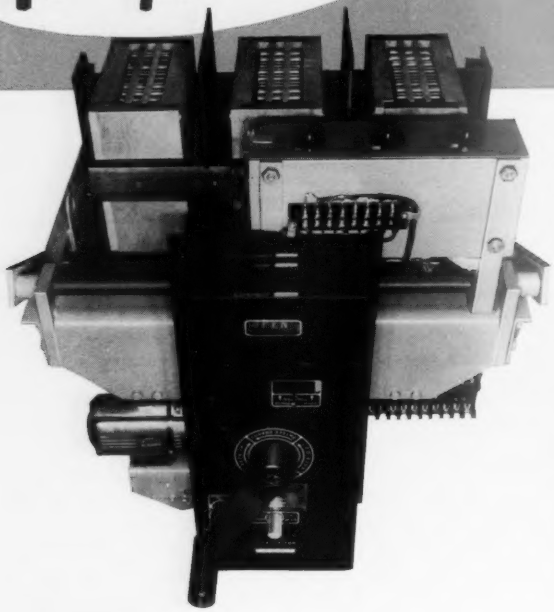
PROTOTYPE SYSTEM components may be identified by Figure 2. Plasma generator is on extreme left, vacuum system on extreme right. Accelerator is identified by magnetic coils on either side of confining tube.



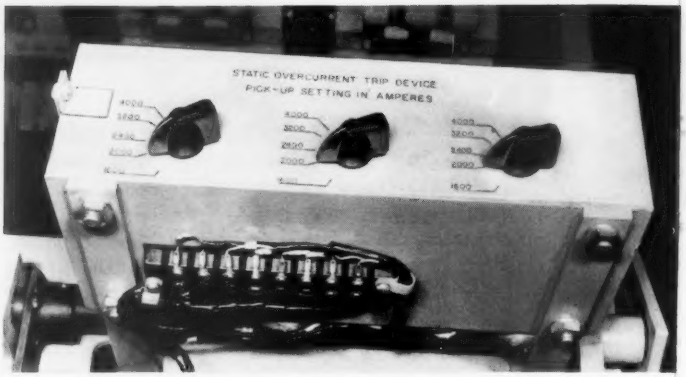


BASIC ACCELERATOR COMPONENTS include horizontal water-cooled electrodes, magnetic coils and water-cooled containment chamber. Plastic tubing is part of cooling system, and tank on right is test chamber. **(FIGURE 3)**

New Accuracy ...FOR LOW VOLTAGE BREAKER TRIPPING



TOP FRONT VIEW of static tripping device mounted on a 75,000 amperes interrupting capacity electrically operated air circuit breaker. New static trip device provides accuracy not previously available. **(FIGURE 1)**



NEW STATIC OVERCURRENT trip device needs no external power source for breaker tripping. Circuit components are embedded in epoxy-resin which greatly reduces the need for maintenance. **(FIGURE 2)**

by **N. M. RUSSAK**
Boston Works
Allis-Chalmers Mfg. Co.

Static trip device without moving parts or contacts provides sensitive trip without external power source.

CIRCUIT BREAKER trip coordination, often a problem with low voltage breakers, can now be approached with new, more sensitive trip characteristics. Static overcurrent trip devices now provide accuracy and trip characteristic control not available in direct-acting trip devices.

Composed of diodes, resistors, capacitors, and transistors, the device has no moving parts or contacts. It functions as a conventional direct-acting series trip unit in that it is self-contained and does not require any external power source for breaker tripping. Timing and tripping functions are performed by utilizing energy from small current transformers mounted on the circuit breaker.

Figures 1 and 2 show the static tripping device mounted on a 600 volt, 75,000 amperes interrupting capacity circuit breaker. The device, whose circuit components are embedded in epoxy-resin, making it shockproof and maintenance free, is made up of four sections as indicated in Figure 3. They are:

(1) Rectifier and filter circuits which provide a power supply plus a dc signal proportional to the primary current; (2) a trigger circuit to start the timer when the signal exceeds the preset value; (3) a plug-in timing circuit, independent of the rest of the device, which triggers the amplifier after a time delay depending on the value of the primary current; and (4) an amplifier which energizes the trip coil when actuated by the timer.

An ideal time-current characteristic curve has been superimposed in Figure 4 for direct comparison on a typical curve used in present-day standard breakers. At present, the tripping curve is approximated by the use of the two time-delay devices, one for long and the other for short time delay. These more conventional overcurrent curves have a "hump" or discontinuity between elements identified as long-time delays and short-time delay.

Static trip advantages detailed

Tripping characteristics obtained from the new static trip unit are depicted in Figure 5. The straight sloping line is similar to curves for current-limiting fuses and other protective devices. Much closer coordination with other protective devices on a system is allowed by the straight-line characteristic produced by the static device.

Operating curves of the new unit also indicate that the tolerance range results in a very narrow band width as compared with much wider band widths found in conventional devices. Instantaneous adjustments on all three

phases may be made simultaneously with the turn of a knob. This accuracy, plus better selectivity, will insure continuity of service for equipment protected by breakers equipped with static trip devices.

Time delay is easily adjusted

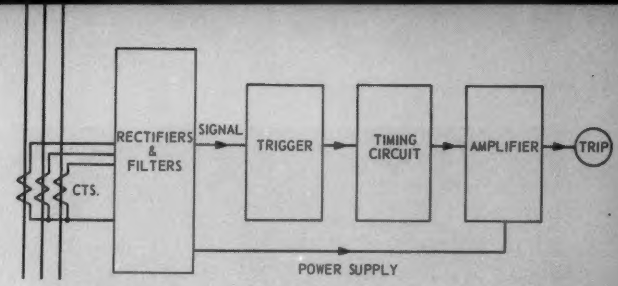
Ideal tripping characteristic for most applications would plot as a straight line on a log-log graph over a considerable range of time and current. Mathematically, this is expressed as time, T, equals a constant, K, divided by current, I, raised to the nth power or

$$T = \frac{K}{I^n}$$

The constant K is the time delay at unity current, the minimum pick-up current for which the trip device can be set to operate. Changing the value of K moves the curve vertically on the graph without changing the slope. The exponent n determines the slope.

By simply changing the "plug-in" timing circuit, time delay can be made long or short as required. The constant K can be varied over wide limits and the slope of the curve can be changed in the same manner. Practical limits of the exponent n can be any value between one and three.

Figure 6 illustrates static trip characteristics for minimum, intermediate and maximum time bands. The present three-part curves (long, short and instantaneous) are simplified by combining the long and short time tripping in one time element. Because these curves are similar to those of fuses, there is better protective device coordination. Existing curves frequently project into the fuse area which prevents 100 percent coordination.



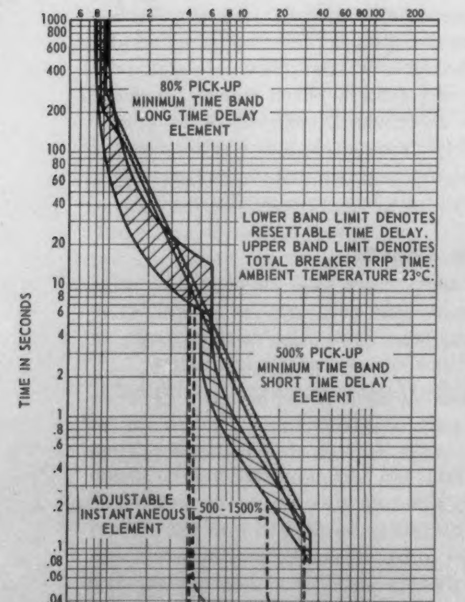
SCHEMATIC OF ELECTRONIC circuit used in the static tripping device indicates its four sections. The device, which has no moving parts, is relatively simple for an electronically operated unit. **(FIGURE 3)**

Short-circuit protection is improved

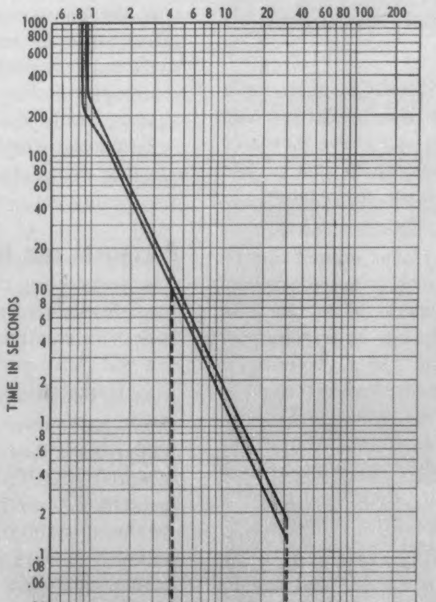
An adjustable short-circuit response over a greater range than is available on existing equipment is obtained with the new device. Instantaneous pick-up is adjustable from 4 to 30 times the minimum pick-up setting of the breaker, as compared with the 5 to 15 times currently available.

Pick-up current can be easily selected over a considerable range. For example, a 600-ampere breaker can be set to trip anywhere between 480 and 1200 amperes by a single adjustment. The device resets quickly if the current decreased to about 90 percent of pick-up value at any time before the breaker trips.

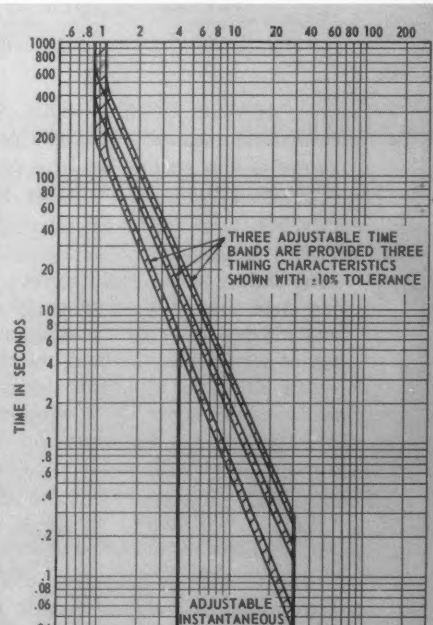
Static overcurrent relays, since their introduction about a year ago, have been well accepted because they can be smoothly coordinated with other power system relaying. Time-current characteristics of the new static trip device, when used with load center substation breakers, can be readily coordinated with primary distribution back-up breakers.



SUPERIMPOSING IDEAL TIME current characteristic curve on typical curve of today's standard low voltage breaker indicates more simple solution of coordination problems with ideal curve. **(FIGURE 4)**

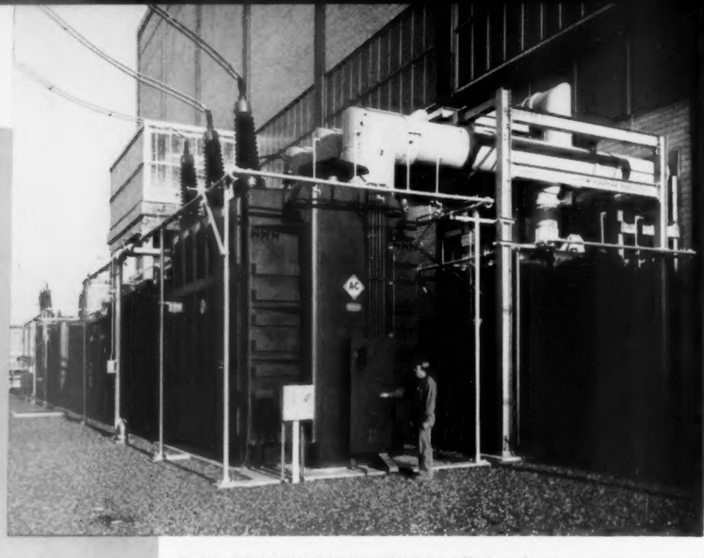


TRIPPING CHARACTERISTICS CURVE of the new static trip unit shows the straight sloping line is similar to curves for current-limiting fuses and other protective devices. **(FIGURE 5)**



STATIC TRIP CHARACTERISTICS for minimum, intermediate and maximum time bands are indicated. Both long-time and short-time characteristics are in a single continuous band. **(FIGURE 6)**

Saving through DUAL COOLING



NEW DUAL-COOLING UNIT installed at large eastern power station. Each generating transformer will carry 350,000 kva when necessary by utilizing interconnected cooling equipment of both transformers.

by **L. W. SCHOENIG**
and
T. H. PROGLER
Transformer Dept.
Allis-Chalmers Mfg. Co.

Multiple-cooling principle ensures additional capacity to handle substation load as well as emergency situations that may arise.

TO PROVIDE CONTINUOUS SERVICE in a more economical manner, a concept of transformer cooling known as dual cooling has been perfected as a means of obtaining capacity which is not subject to loss of life penalties or dependent on low ambient temperature.

This method of cooling can be provided for two or more similar power transformers. Under normal operating conditions the cooling equipment is shared equally and independently by the transformers. With one unit out of service the remaining transformer or transformers utilize all of the cooling equipment. In a two-unit installation the capability of either with double cooling is 133 percent of the maximum individual self-cooled, forced-air-cooled or forced-oil-cooled rating. At this rating temperature rise does not exceed 55 degrees C average copper or 65 degrees C hottest spot. Additional capacity may be gained using conventional loading practices.

The manner in which the cooling capacity is transferred from one unit to another is flexible and can be suited to match individual applications. The cooling equipment is either physically moved from one unit to another or is interconnected through a series of pipes.

Flexibility indicated by various arrangements

Figures 1 and 2 show one method of providing increased capacity on transformers having either self-cooled or forced-oil-cooled ratings. The cooling equipment from the second transformer is connected as shown on the first unit. Since each radiator or heat exchanger is valved, the change can be made without a service interruption.

Cooling equipment can be interconnected as shown in Figure 3. With this arrangement valves adjacent to the transformers are normally open, while the valve between the coolers is closed. All of the cooling mechanism can be used on one transformer by opening the center valve and closing the proper valve adjacent to the transformer.

If the new arrangement is used because of a service interruption of one transformer, the cooling equipment to be used in connection with the other unit should be thoroughly flushed and cleaned. Each radiator, heat exchanger, and pipe is provided with valves to permit isolation and simplify cleaning. In this way the amount of oil to be handled and time required to clean and move the cooling equipment are kept to a minimum.

Purchases can be delayed

The dual-cooling concept enables the use of smaller transformers while ensuring that extra capacity is available to cope with emergency conditions. Also, in many cases, its use will defer purchase of additional transformers.

Many distribution substations utilize two duplicate three-phase power transformers to supply a given load. If a 20,000-kva load is to be handled, two transformers rated 12,000/16,000/20,000 kva OA/FA/FA, 15,000/20,000 kva OA/FA, or 20,000-kva FOA would be used. The maximum rating of the transformers, in each case, would be equal to the load to be handled by the substation. In normal operation the load is divided between the two transformers. However, during routine maintenance or emergency conditions, each transformer would safely handle the total substation load.

If capacity of these substations increases beyond 20,000 kva, an additional transformer is normally added. This unit is not required for normal load but to ensure adequate capacity to handle the total substation load with one unit out of service.

Purchase of an additional transformer could be delayed if some means of increasing the existing capacity could be found. The new concept of cooling is a solution. The capacity of either of the transformers can be increased $33\frac{1}{3}$ percent to a rating of 26,667 kva if the transformers are designed for dual cooling. With this arrangement the third transformer would not be required until such time as the normal substation load exceeded 26,667 kva. Since this load is divided between the transformers, each will be loaded to about $\frac{2}{3}$ capacity in normal operation. During routine maintenance or under emergency conditions, each *Dual-Cooled* transformer can continuously carry 26,667 kva with no loss of life.

Since load growth is usually gradual, 6 or 7 percent per year, the purchase of the additional transformer can be deferred four or five years if dual cooling is utilized. A 6 percent annual increase, based on 20,000 kva, results in a 26,700-kva load in five years. A 7 percent annual increase results in a 26,200-kva load in four years. With carrying charges of 15 percent per year, savings resulting from delayed purchase of the transformer, assuming it is to be a 67-kv unit, would be approximately $9000 per year or $36,000 to $45,000 total, depending upon load growth.

Initial cost is at minimum

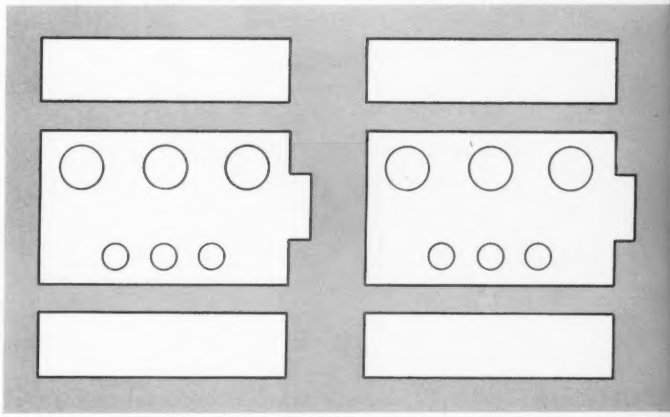
To handle a maximum capacity of 41,667 kva, it is common practice to use two 25,000//41,670-kva self-cooled //forced-air-cooled units or two 41,670-kva forced-oil to air-cooled units. Each transformer has a top rating equal to the maximum load; therefore continuity of service is virtually assured. With the new concept in cooling, two 18,750//31,250-kva self-cooled//forced-cooled or 31,250-kva forced-oil to air-cooled transformers can be used in parallel to handle the 41,667-kva load. Dual cooling increases the 31,250-kva rating to 41,670 kva, thus permitting one unit to carry total station load when required.

Arranged in this manner, the smaller transformers assure the same continuity of service as conventional 41,670-kva top rated units. The use of smaller units permits savings in initial transformer cost of approximately 20 percent. The actual dollar saving, of course, would depend upon the characteristics of the transformer, kv class and other basic considerations.

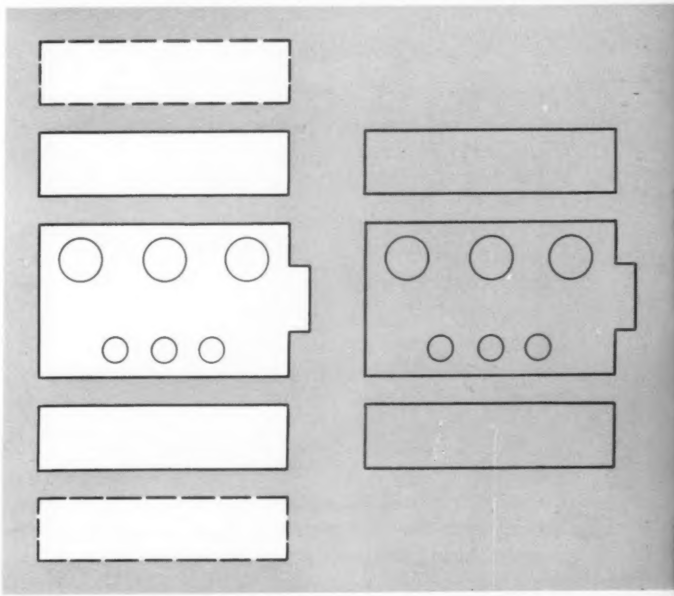
Substation transformer application described

Figure 4 shows a large bulk power substation where power is supplied to the station at 138 kv and distributed to an extensive loop system at 14.1 kv. Each transformer is a 90,000-kva FOA unit complete with plus or minus 10 percent LTC equipment for voltage control and has two 45,000-kva low voltage windings.

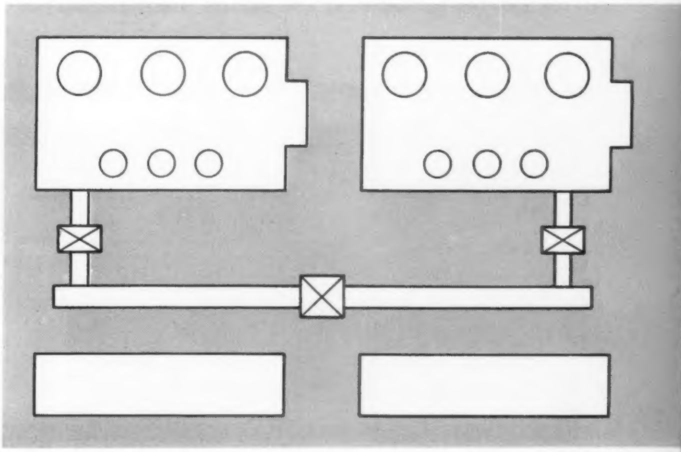
To ensure maximum reliability, two 120,000-kva FOA units were considered so that each transformer could carry the full load of the station if necessary. To provide for future load growth, the substation was designed for



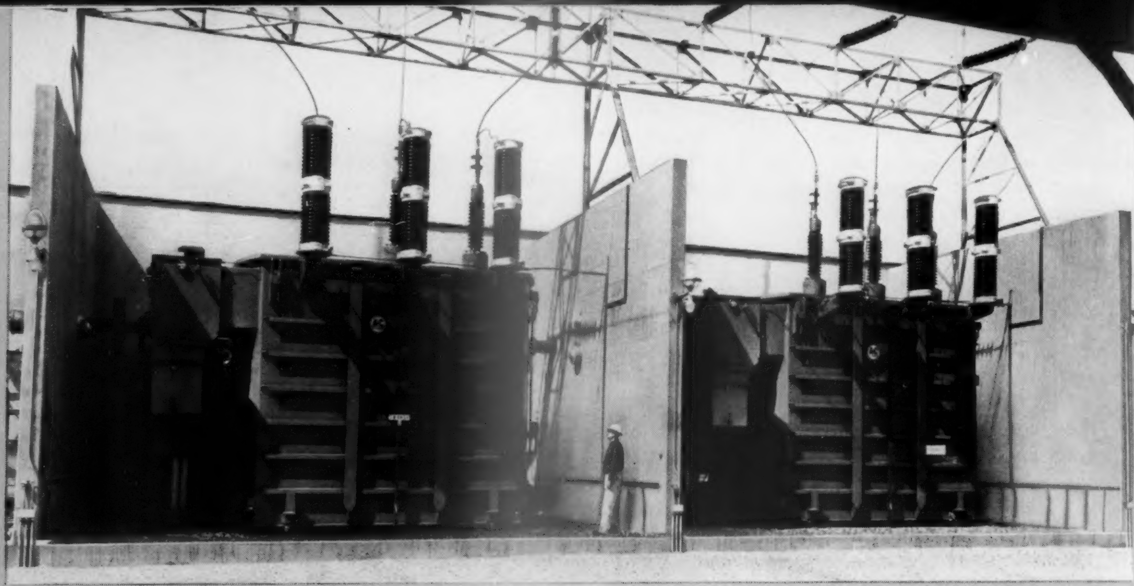
CONVENTIONAL cooling systems can be used with OA, OA/FOA, or FOA transformers. **(FIGURE 1)**



PHYSICALLY transferring cooling equipment converts above system to dual cooling. **(FIGURE 2)**



INTERCONNECTING cooling equipment converts conventional system to dual cooling. **(FIGURE 3)**



MIDWESTERN POWER UTILITY has two 90,000-kva load tap-changing transformers in large metropolitan bulk power substation. Use of dual cooling reduced initial transformer and foundation costs. **(FIGURE 4)**

the addition of a third unit. The new concept in cooling offered many advantages for this application. Units rated 90,000 kva were chosen since each would have a 120,000-kva capacity, the present substation load, with dual cooling. The use of smaller transformers resulted in saving in initial transformer and foundation costs, and a reduction in substation area. The saving in initial transformer cost was approximately $120,000.

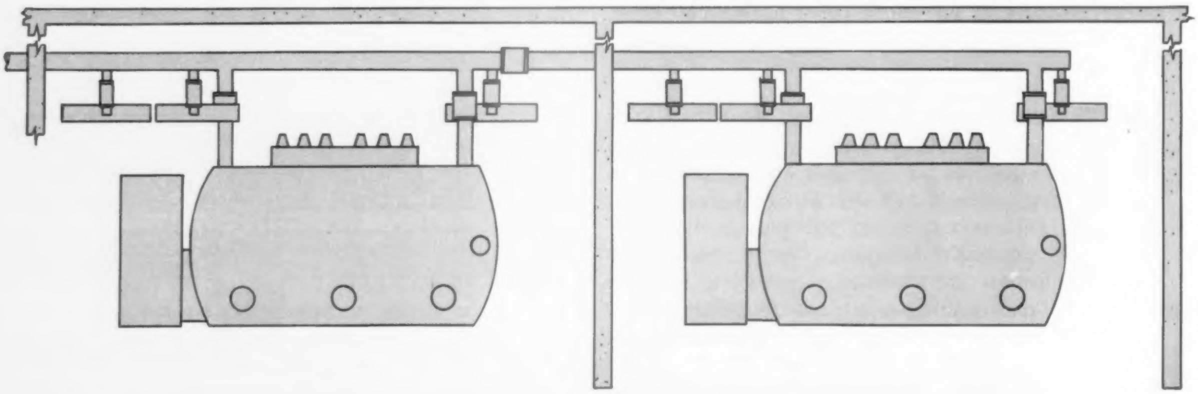
Cooling systems of these transformers are connected as shown in Figure 5 and designed so that each transformer can be cooled independently of the others or part or all of the cooling can be utilized by any of the transformers. The capacity available through the flexibility of the arrangement is shown in Table I. Substations designed in this manner permit maximum utilization of transformer cooling equipment, thereby substantially increasing station capacity during special or emergency conditions.

Largest *Dual-Cooled* transformer, in service on a midwestern power company system, is rated 290,000/460,000 kva, 230/138 kv. Power from the generating station is fed into the substation at 230 kv and is transformed for distribution throughout the system at 138 kv. Figure 6 shows the first of the three units which will take advantage of dual cooling and low ambient temperature to carry emergency winter peak power demands.

This transformer's cooling system is designed to readily accommodate the oil-to-air heat exchangers from one of the other units. The addition of coolers is easily accomplished and can be done with the transformer in service. In a matter of hours the capacity of the transformer is increased 33 percent. With two units in the station and assuming a 580,000-kva load, the new cooling assures a firm capacity of 67 percent or 375,000 kva. With three units in the station and assuming an 870,000-kva load, a firm capacity of 78 percent, or 665,000 kva, is provided.

Dual cooling also effective for generator transformers

Dual-Cooled transformers can be used in generating stations as in substations. They are particularly applicable when two half-size transformers are used, as is frequently the case with cross-compound turbine-generators.



CONNECTED AS SHOWN, the cooling system of the installation in Figure 4 is so arranged that each transformer can use part or all of the cooling equipment independently of the other unit if needed. **(FIGURE 5)**

Selecting the principle of dual cooling for generator transformers minimizes the loss of system economy due to reduced plant output with maintenance or service outages. Although the reliability of transformers is better than most any other piece of equipment on a power system, accidents do happen and must be considered. The use of two half-size transformers ensures 50 percent firm capacity, but with dual cooling firm capacity is increased to 67 percent.

At an eastern electric company's station each transformer will carry 350,000 kva by utilizing the cooling equipment of both transformers. The cooling equipment is mounted on piping and is arranged to operate as two separate cooling systems or a single system for either transformer. This arrangement can be accomplished easily and quickly by opening and closing valves.

Figure 7 illustrates a slightly different cooler arrangement used for the 192,000/265,000-kva, 230 to 18-kv units in a western electric company's power plant. In this case each transformer has a normal rating of 192,000 kva and will carry 265,000 kva using all the cooling equipment. The use of two half-size transformers with dual cooling makes certain that a firm capacity of 265,000 kva or 67 percent normal is available with one transformer out of service.

Saving benefits for many systems

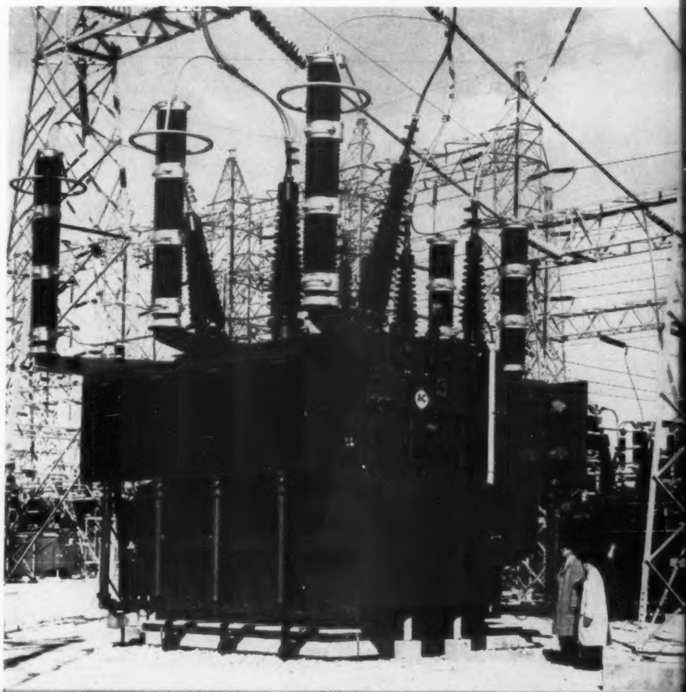
The arrangement of transformers and coolers is very flexible and can be designed to meet virtually any given situation. Space limitations, center to center spacing of transformers, and preferred cooler arrangement can be considered in the layout.

To ensure continuity of service in the most economical manner, special consideration should be given to *Dual-Cooled* transformers for both generator and substation applications. The savings resulting from the use of smaller transformers or from the delayed purchase of additional transformers can be experienced on practically all systems.

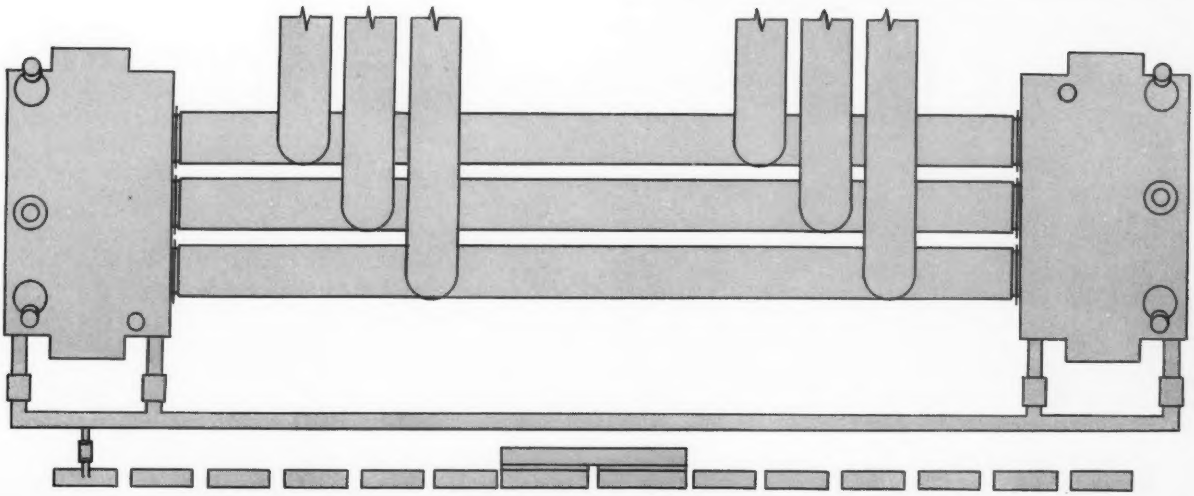
TABLE I

Transformer	Sets of Cooling Equipment	MVA Capacity
1	1	90
1	2	120
1	3	140
2	2	180
2	3	210
3	3	270

Flexibility and increased firm capacity

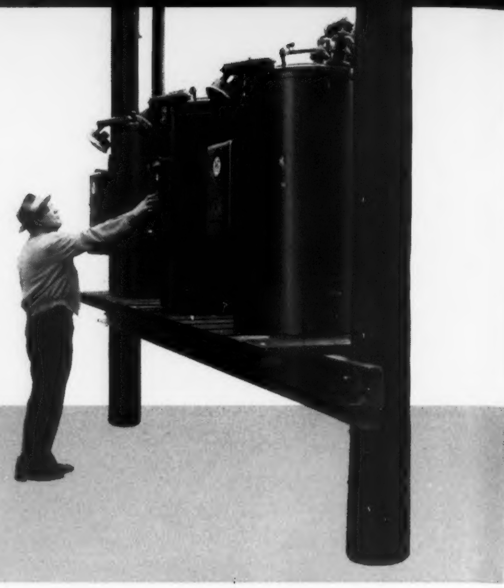


LARGEST *DUAL-COOLED* TRANSFORMER, rated 460,000 kva, 230 kv, ensures continuous service at this Midwest substation. **(FIGURE 6)**



IN ANOTHER COOLING ARRANGEMENT, each generating transformer is rated 265,000 kva when all cooling equipment is used for a large Pacific Coast utility. **(FIGURE 7)**

System Changes Bring INTEGRAL REGULATOR DESIGN



TYPICAL PLATFORM INSTALLATION of three 50-kva, 2500-volt distribution regulators is at a convenient height for resetting the tap position indicator with the electrical reset button on the control panel.

by E. J. ADOLPHSON
Regulator Department
Allis-Chalmers Mfg. Co.

Trends in system operation and maintenance requirements have brought new conveniences to distribution regulator designs.

POWER COMPANIES are taking more comprehensive records of load swings and are systematically checking regulator operations. This information is helping system engineers to plan for load growth. Convenience in making these readings and the resetting of position indicators has become more important.

More control panels of pole-mounted regulators are being mounted at the base of the pole to facilitate adjusting voltage settings or checking the operations counters, thus saving time and reducing the need for pole climbing.

Feeder voltage regulators combine a rather large number of equipment types requiring careful engineering. These include a transformer device similar to a distribution transformer, a heavy current and high voltage interrupting switch, a voltage and current sensitive control, and instrument transformers.

Integral design simplifies handling

To simplify untanking, a new position indicator was developed to mount on the regulator cover rather than on the tank. The cover-suspended regulator with its cover-mounted position indicator and control panel can be untanked for inspection and minor repair without disconnecting power or control leads. The position indicator has electrically resettable drag hands with the reset button in the control panel.

The new designs make use of a number of distribution transformer parts as well as manufacturing facilities. The general arrangement of parts was made as standard as possible for all ratings. Stocking and spare parts problems are minimized by reducing the variety of such items as the bushings required for the line. Crimped joints for cables and leads as large as 600 MCM and the necessary tooling were developed. These joints have proved to be equal to brazed joints in thermal cycling and high current tests.

Appreciable space was saved in the regulator by using through-type current transformers. Size and weight of potential transformers were also reduced by the wound core construction.

Short-circuit strength increased

Unit weight and size reductions were made using a wound core with a rectangular coil. A series of studies on coil design was made to assure maximum mechanical strength under short-circuit current operation. The maximum forces tending to distort the coil are exerted when full winding is used with a short-circuit current based on the 100-percent current rating. The only forces of consequence were radial forces that tend to make the outer winding more round and compress the inner winding. No axial forces are encountered because the magnetic ampere-turns of the winding balance in the axial direction. Each tap section of the winding occupies a full layer of the winding to keep the windings balanced regardless of tap position.

Regular short-circuit tests were made in insulating oil. However, a few tests were made with the core and coil in air to facilitate the taking of high speed color movies at 2000 frames per second during short-circuit tests. An oscillogram of the short circuit was superimposed on the film to show coil motion during each cycle of current.

Similar short-circuit and through-current tests were made on the tap-changing mechanism. High speed movies with the superimposed oscillogram were also used in these tests. Interesting data and visual records were ob-

tained while checking the new designs. These visual records showed contact movement and under what current conditions serious contact arcing might be expected.

Distribution system needs are met

The safety and convenience of line men working on both power and telephone lines has brought attention to the overall regulator size and weight. Typical weight and size reductions are shown in Table I.

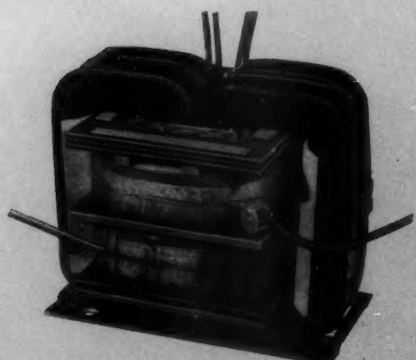
Power distribution practices are constantly changing to simplify operating and record keeping. These system changes have given impetus to a major voltage regulator redesign program. The resulting introduction of an integrated design has provided a compact regulator with many design improvements to meet modern system needs.

TABLE I

COMPARISON OF OVERALL HEIGHTS AND WEIGHTS

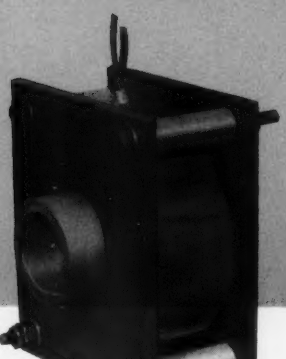
Rating		Overall Height		Total Weight	
Kva	Voltage	Old	New	Old	New
25	2500	80 in.	54 in.	1515 lbs	965 lbs
100	2500	79	83	3100	2428
50	5000	80	63	1750	1440
38.1	7620	74	64	1305	1168
76.2	7620	97	75	2300	1776
167	7620	96	91	4000	3320
144	14400	93	98	3880	3530

NEW DESIGN 76-kva regulator, foreground, can be compared to earlier design, center, for size, features and convenience.



NEW WOUND CORE construction using continuous-strip cold-rolled grain-oriented steel has reduced potential transformer weight to less than half that of earlier designs.

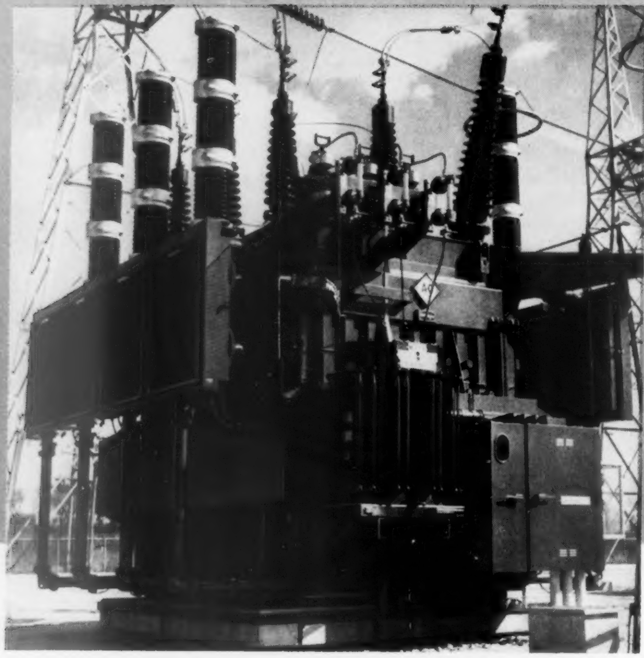
UNIT CONSTRUCTION greatly simplifies handling of new regulator. The cover-suspended regulator can be untanked as a complete unit.



TOROIDAL WOUND current transformer weighs about 17 percent less than previous designs. The new design provides same control accuracy. Spiral wound continuous strip core is used.

PARTIALLY ASSEMBLED NEW REGULATORS automatically roll down the assembly line at the Gadsden (Ala.) Works. Single-phase distribution regulators, including units rated 50 kva and below, are manufactured here. The entire regulator assembly procedure — from the time core steel is received, through core and coil construction, connecting mechanisms, preliminary testing, oven dryout, tanking, and final testing — is handled via conveyor system.
Allis-Chalmers Staff Photo by Harold Shrode

MAIN TRANSFORMER *POWERS* AUXILIARY LOADS



by **J. A. EBERT**
Transformer Dept.
Allis-Chalmers Mfg. Co.

MOUNTING AUXILIARY TRANSFORMER on main unit is conventional means of obtaining 220 or 440-volt power to operate transformer cooling equipment. This is economical where a 15,000-volt, or lower, winding is available. **(FIGURE 1)**

Here are ways to obtain self-contained low voltage power for station auxiliary loads and cooling equipment.

ADVANCES IN INSULATION coordination and over-voltage protection have made the large power transformer so dependable that utilities and industry can take full advantage of the economy of one big unit over several smaller ones. With this trend to larger and larger units, forced-oil cooling has become more important as a tool to reduce physical size for a given kva rating.

A forced-cooled transformer is only as good as the power supplied to its pump and fan motors, since it can be excited for only a few hours without its cooling equipment in operation. The auxiliary power supply is therefore of prime importance to the utility or industry using a modern forced-cooled transformer.

The majority of power transformers are located where low voltage power from the normal distribution system of the utility is available. When such is the case, it is most convenient and reliable to use this source for operating the cooling equipment and auxiliaries of the transformer.

However, for transformers in remote locations, where auxiliary power is a problem, and for those units which must be self-contained and independent of customers' normal low voltage distribution source, several methods of providing auxiliary power integral with the main power transformers are available.

Normal method mounts auxiliary on main transformer

The objective is to provide 220 or 440-volt power to operate transformer cooling equipment and auxiliaries requiring 10 to 75 kva.

Conventional method of accomplishing this is to mount an auxiliary transformer on the main unit, as shown in Figure 1. This involves electrical connections from the main to the auxiliary transformer and is economical where a 15,000-volt or lower voltage winding is available.

For protection, lightning arresters and external fuses, or internal fuse links in the auxiliary transformer, are provided. The secondary of the auxiliary transformer then must be taken in conduit to the control box and motors. An external installation is usually protected by a screen or housing to maintain protection standards for operating personnel, unless out of the way mounting is possible.

When the voltage available from the secondary or tertiary of the main unit is above 25 kv, however, mounting an external auxiliary transformer becomes difficult and impractical. The electrical clearances required to mount the higher voltage auxiliary transformers make the physical dimensions of the assembly too great to be economical. Other methods are more advantageous.

Several other methods are available

One of these other methods is provision of an internal auxiliary transformer under oil in the main tank or in a separate compartment. Its primary is connected to a low voltage winding of the power transformer, as illustrated in Figures 2 and 3. The primary of the auxiliary transformer must be fused to protect the power transformer winding in case of a failure of the auxiliary.

When the auxiliary transformer is installed in a separate oil-filled compartment, an extra set of bushings must be used to bring leads from the transformer winding through a barrier to the auxiliary transformer primary. If these bushings have the same current rating as the winding, the fuse can be mounted in the separate auxiliary compartment. A special fuse for use under oil must

be provided whether the auxiliary transformer is in the main tank or in a separate compartment. Provisions must also be made to contain the fuse when it functions, to keep it from damaging the main transformer. Replacing a fuse requires draining all or part of the oil in the auxiliary compartment or main tank. The fuses are accessible through a gasketed manhole.

Additional space is required inside the transformer tank for the internal auxiliary and connections, with the result that the overall size of the main tank may be increased. When the auxiliary is in a separate compartment, the size of the main tank still must be increased to allow space for main winding leads to be brought to bushings in the auxiliary compartment. In either case, the increased tank dimensions could have an adverse effect on shipment of the unit. Both the above methods are more economical than using an external auxiliary transformer when the main transformer has only 25 kv or above available for connection to the auxiliary.

A fourth method available is to tap a suitable voltage directly from the transformer winding and connect to an auxiliary transformer to provide the correct secondary voltage. This has the same effect as the method outlined previously, in that the power transformer itself must be protected by fusing the auxiliary transformer primary.

Voltage can be directly supplied

Bringing a voltage for operating auxiliaries and cooling equipment motors directly from an additional separate winding on the power transformer is also possible.

This arrangement is especially desirable and economical when the lowest voltage available for connection to an auxiliary transformer is 69 kv or above. It may even prove satisfactory where a voltage as low as 34.5 kv is available. To do this, several turns of a conductor can be wound around one yoke of a shell-form transformer. Each turn gives a voltage equal to one half of the volts per turn. This conductor of several turns is an auxiliary winding on the transformer, and its impedance to the other windings of the transformer is high. Because of this impedance the short-circuit current of the winding is small.

A three-phase delta or open-delta voltage can be supplied by providing the auxiliary windings on three phases of the main core. An autotransformer can be provided if the main transformer volts per turn is such that a whole number of turns does not provide the correct voltage.

Such a power source is shown in Figure 4. The winding for the auxiliary power is usually insulated for 15-kv class (34-kv test). Since the auxiliary winding is usually located in an area of low voltage stress, it does not materially add to the size of the transformer.

Leads can be brought out the side of the cases, near the core, or out of the cover. Small barrier bushings or a gasketed terminal box can be used to bring the leads out of the case. A cable conductor with terminal box termination can be used where the power requirement does not exceed approximately 25 kva, three phase. Above that level, bus bar and barrier bushings are preferred.

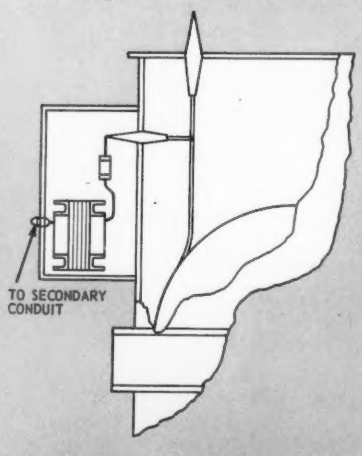
Advantages and disadvantages noted

An external auxiliary transformer is most reliable because of its easy accessibility. It requires lightning arresters and fuses for protection. These, along with bushings and other external parts, are exposed to the weather and require maintenance. The use of an internal auxiliary transformer has the advantage that no external devices are required, and therefore no maintenance problems are caused by exposure to weather. It has the disadvantages of not being easily accessible and of generally increasing the main transformer tank dimensions.

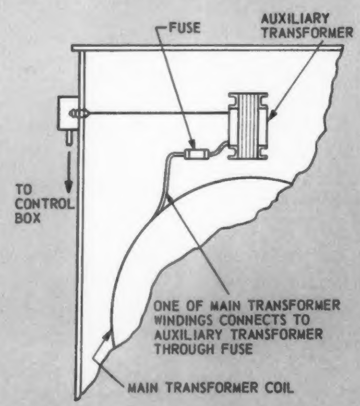
A separate winding around the core yoke section requires no external protection and only a minimum amount of space in the main transformer tank. The disadvantage is the same as for any internal assembly — poor accessibility for any necessary servicing.

There are many possible variations of the schemes outlined and each one can be adapted to fit a particular need. Many transformers using one of these schemes or a variation of them are in service. Each will do the job of providing a self-contained source for cooling equipment and auxiliaries with safety and efficiency.

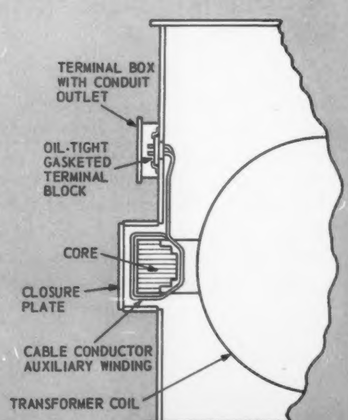
AUXILIARY TRANSFORMER in separate compartment, with primary fused, supplies a three-phase voltage for secondary loads. **(FIGURE 2)**



INTERNAL AUXILIARY TRANSFORMER under oil in main tank with primary connected to low voltage winding of the power transformer. **(FIGURE 3)**



A CABLE CONDUCTOR with terminal box termination can be utilized where power requirement does not exceed 25 kva, three phase. **(FIGURE 4)**



NEW PERFORMANCE GAINED WITH STATIC RELAYS

by **F. T. FREE**
Relay Section
Allis-Chalmers Mfg. Co.

Static relays provide a new approach to system overcurrent and fault protection problems. Their performance characteristics are attracting the attention of power distribution engineers.

THE NEED FOR IMPROVED service continuity, coupled with overall distribution system economy, guided the recent relay developments that culminated in the introduction of the static relay system. Faster circuit breaker operating and arcing times, improved fuse characteristics, and better definition of equipment thermal and mechanical limits were considered important factors in the design of the new protective devices.

The relay system comprises four separate operating sections: input section, inverse timing section, instantaneous section, and finally the tripping section. The relationship these sections have to each other is shown in Figure 1.

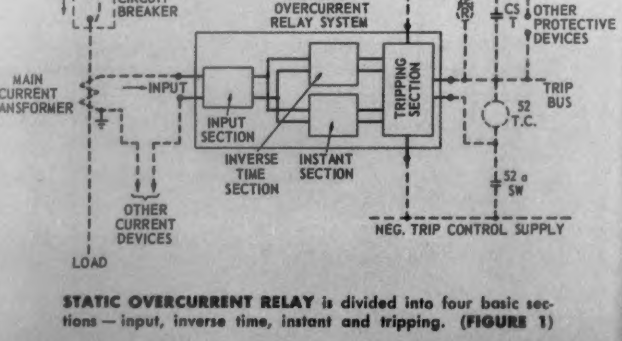
The input section has a multi-ratio current transforming function to establish a low energy input to the paralleled inverse timing and instantaneous sections. It also affords means of minimizing the burden reflected back into the main current transformer's secondary circuit; provides transformer coupling of the relay to the main current transformer; and finally affords protective benefits to the semiconductor circuitry.

The inverse timing section functions to monitor the output signal from the input section for signal excursions, whereupon it statically switches the excursion to an inverse "RC" timing circuit. The signal level at which this switching takes place is fixed by design. This fixed threshold is equal to the output of the input section for each of its ratio taps. The ratio tap selection of the input section is equivalent to the tap current pick-up selection in the induction disc relay. The rate of charge build-up on the timing circuit is also adjustable. This control in the inverse timing section is equivalent to the time dial selection on the conventional relays. At a designed fixed level of potential across the capacitor, the normally inactive relay statically switches "on" and conducts a power pulse to the tripping section. Two additional operations occur with this later switching: first, trip indication is registered; second, the timing capacitor is drained of its charge, resetting the timing circuit.

The instantaneous section functions in a manner similar to the inverse timing section without the time-delay circuit. The adjustment of the signal level at which this section power pulses the tripping section is the only adjustment required.

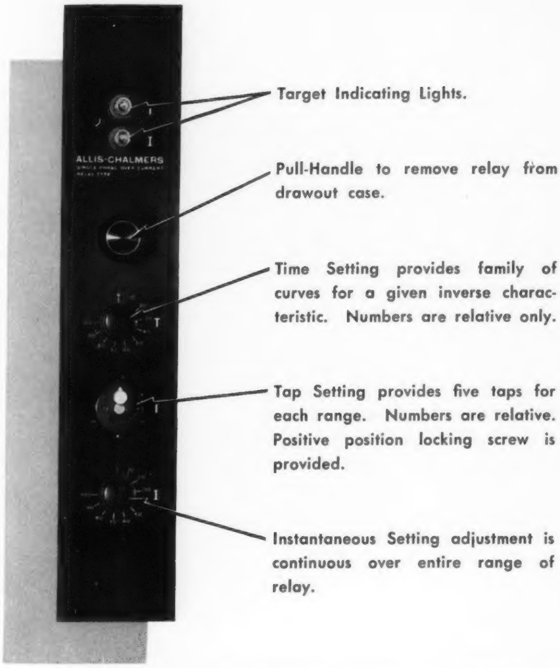
The tripping section is a static switch which is switched "on" by the power pulse signal emanating from either the inverse timing section or the instantaneous section. In its "on" state, this section completes the dc tripping coil circuit of the circuit breaker or other supervising device and conducts the actual operating current.

Figure 2 shows a typical face plate of a static overcurrent relay. The lights located at the top of the face plate provide relay operation indication. The top light is the time trip indicator and the lower light is the instantaneous trip indicator. In the center of the face plate is the indexed time dial. This dial has the same function as the time dial of an induction disc relay. The tap dial selects the tap current setting within a tap current range. The tap current range is determined by the input section ratio tap selection. The indexed control at the bottom of the



STATIC OVERCURRENT RELAY is divided into four basic sections — input, inverse time, instant and tripping. (**FIGURE 1**)

face plate is the instantaneous dial which selects the instantaneous trip current setting.



CONVENIENT EXTERNAL ADJUSTMENTS are provided for the static relay functions. Target lights show operation. **(FIGURE 2)**

Characteristics compatible with existing installations

The static overcurrent relay has been designed to initially possess certain basic performance characteristics which allow it to be compatible in both application and operation with the conventional induction disc overcurrent relays. Foremost of these are the inverse time-current curve (TCC) characteristics. Figures 3, 4, and 5 show the short-time, inverse-time, and very-inverse characteristics, respectively. These curves are deliberately shaped in the familiar manner for coordination purposes and also to facilitate application of these relays with a minimum of special effort. As more experience is gained, new and more useful characteristic curves will be made available. In the static relay design, control of these curve shapes is considerably broadened.

Similarly, tap current ranges, time lever ranges, and instantaneous trip ranges have been designed for complete application compatibility with existing conventional induction disc relays. Departure from these characteristics will be made carefully and deliberately, with utility of performance the predominant consideration.

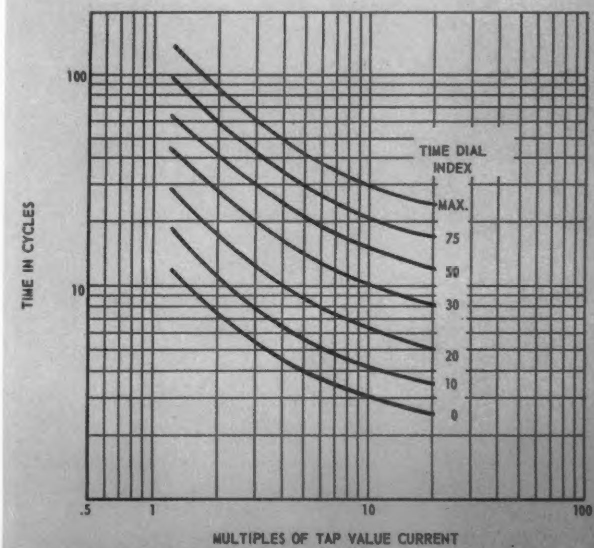
Static overcurrent relays generally perform with a preciseness inherent in electronic circuitry. This preciseness is not economically obtainable in the induction disc type relay. The more notable are these: pick-up sensitivity, fast response time, sharp drop-out, and relatively instantaneous reset time.

Pick-up sensitivity and fast response time each result to a large degree from the fact that static relay operation is completely free of mechanical friction and mass inertia. While high speed switching has been attainable with electronic circuits for some time, the transistorized computers of today attest to the speed and reliability of equipment using solid state devices. Consequently, plus or minus 1 percent pick-up sensitivity and relay response times in the order of a few microseconds are not unusual.

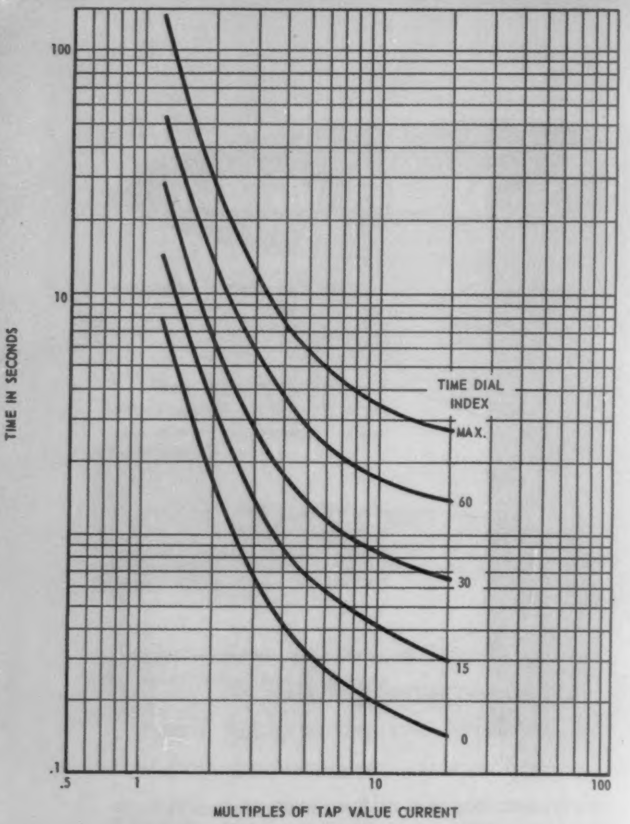
Fast reset provided

Overcurrent relay reset times become more and more significant as power distribution systems grow and become more complex, demanding closer relay coordination and protection tolerances. Typically fast reset time response of the static relay is illustrated in Figure 6 by comparison with reset time response of the induction disc relay. Both relay samples have very-inverse type TCC's, with each adjusted to "time out" at identical times for the same applied current. The dashed curve from time zero depicts the induction disc type relay's disc displacement as a function of time to point *A* where its contacts make to initiate tripping. Displacement *A-B* represents contact overtravel and wipe. Let us assume that the circuit breaker trips and also clears the fault during this overtravel; the disc would then begin to reset from point *B*. The ensuing reset time from *B* to *C* of the very-inverse type induction disc relay is approximately equal to the operating time for 1.4 times minimum relay closing current and is essentially independent of the relay design constants.[4]

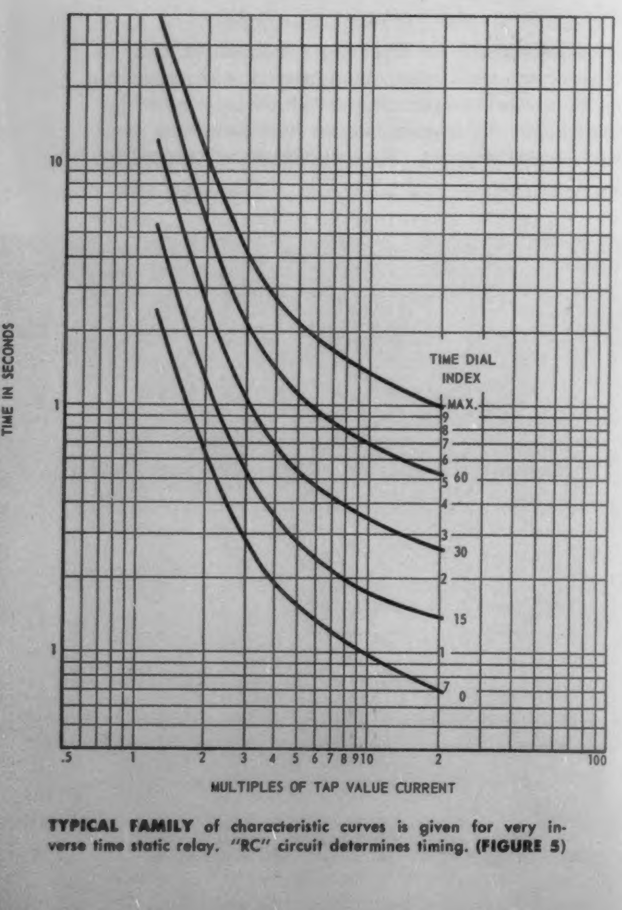
The solid curve from time zero illustrates the charge build-up of the static relay timing section with point *A* being the threshold magnitude at which the inverse timing section triggers the tripping section into conduction and initiates breaker tripping. Note the absence of overtravel.



TIME-CURRENT CURVES are shaped for system coordination. Characteristics of typical short-time relay are given. **(FIGURE 3)**



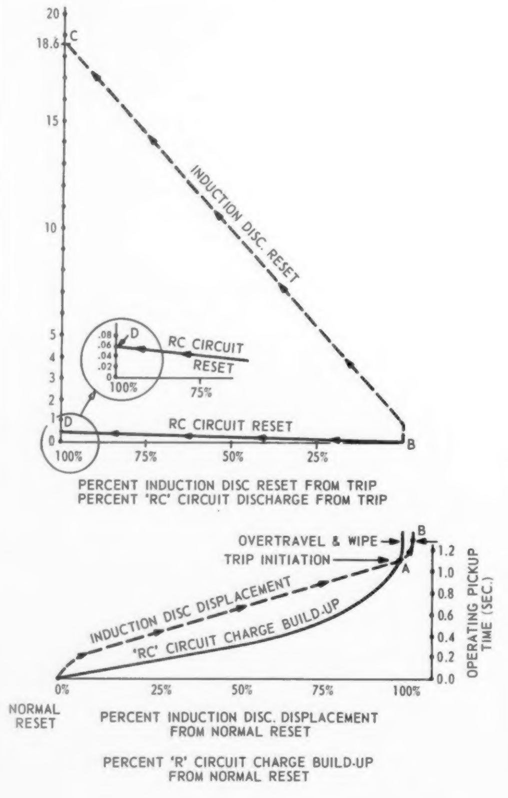
FAMILY OF CURVES is provided by setting of time index dial. Typical inverse-time relay characteristic is given. **(FIGURE 4)**



TYPICAL FAMILY of characteristic curves is given for very inverse time static relay. "RC" circuit determines timing. **(FIGURE 5)**

Again, assuming the breaker has cleared the fault at point *B*, the static relay resets to point *D*. The magnitude of charge at any given instant on the inverse RC timing circuit correlates to the rotary displacement of the induction disc at that same instant. Thus, it is seen that resetting the static relay requires only the removal of charge on the timing circuit. This can be accomplished a number of ways and is completely independent of the minimum operating current of the relay. Significant also is the possible control of the rate of charge drain-off from the timing circuit. This control will result in direct adjustment of reset time, and could be varied over a range from a few microseconds to prolonged reset times that approach those of induction disc relays.

A typical system as represented in Figure 7*a* will illustrate reset time significance. Assume conventional coor-



	Induction Disc Relay	Static Overcurrent Relay
Tap	5-Amp.	5-Amp.
Time Dial	4	50 Index
Oper. Time @ 5-Mult.	1.1 Sec.	1.1 Sec.
Reset Time	18.61 Sec.	0.06 Sec.

RESET TIME of very inverse time static relay is compared to reset time of very inverse induction disc overload relay. **(FIGURE 6)**

dination of the main breaker *A* with feeder breakers *B* and *C* as indicated on the coordination plot in Figure 7*b*.

The desirability of very fast reset of the protective relays for the main breaker becomes evident. Upon occurrence of a feeder fault, both the main and the feeder breakers' protective relays will generally pick up.

Relays at *B* will time out and trip, while relays at *A* will have partially timed out. At this stage, coordination may be lost between the main and all other feeders, since a fault on any feeder can easily cause a main breaker relay *A* to operate.

If reclosing relays are used on feeder breaker *B,* the reclosures must be delayed to allow the main breaker *A* relays to reset, otherwise coordination is again lost.

Relay overtravel resulting from mechanical inertia and the necessity of contact wipe in the induction relay are factors which relay engineers have learned to tolerate. This undesirable limitation is accommodated by allowing more coordination time between the selected time current curves of the circuit protective devices. When using a static relay, this additional allowance can be omitted. Improvement in coordination is illustrated in Figure 8.

Coupled with the extremely fast reset characteristics is the very high drop-out to pick-up ratio maintained. This ratio loses some of its importance if fast reset is inherent to the relay. Yet it is desirable to have as high a ratio as possible in order to minimize the "dead band." The values shown in Table I are representative of those obtainable in static designs. This compares with values of approximately 0.90 to 0.95 for induction types.

The improved characteristics made available by the use of static overcurrent relays will provide better system performance in both reliability and continuity of service. In addition, economies can be realized where present system performance is adequate. Perhaps some of the most beneficial improvements effected by the use of static devices will be uncovered after protection engineers have had more opportunity to study and apply the improved characteristics to their systems.

TABLE I

Static Relay Type	Drop-out/Pick-up Ratio *
Short time	.985
Inverse time	.983
Very inverse time	.981

* Values at minimum Time Dial Index

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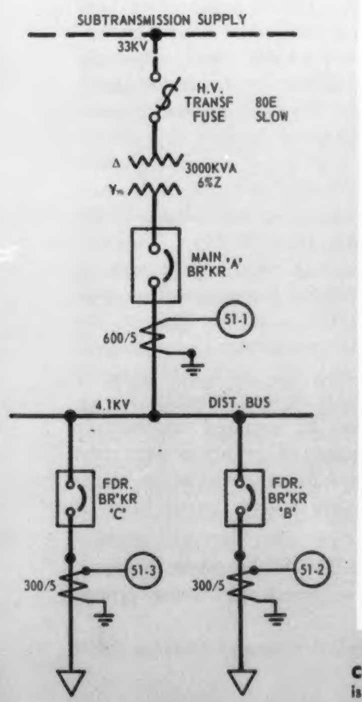
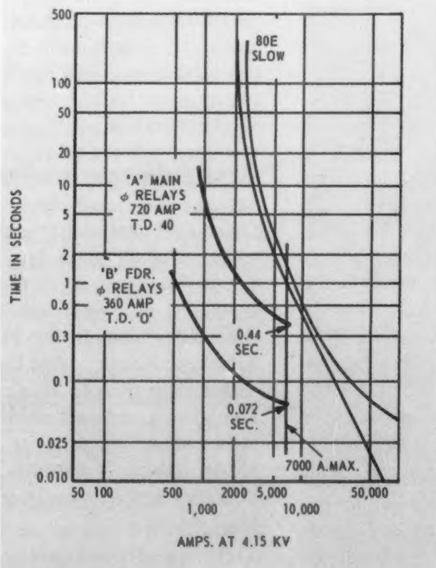
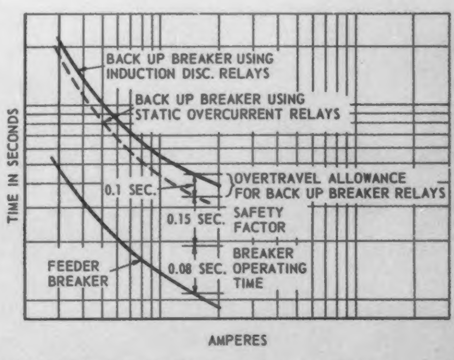




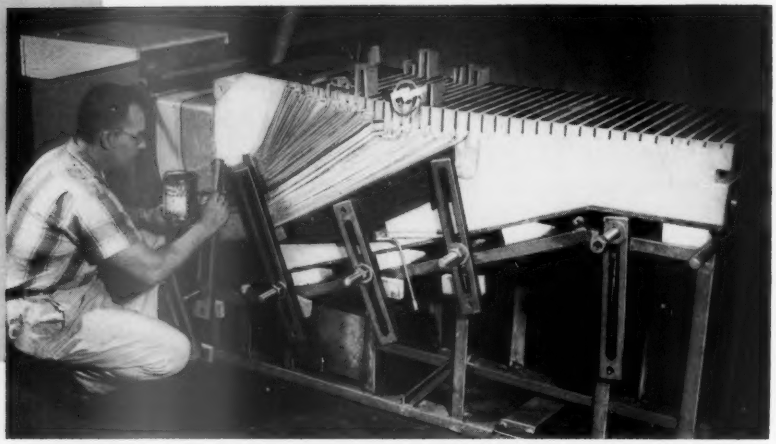


OVERTRAVEL ALLOWANCE made for induction disc relays is not needed for static relays. **(FIGURE 9)**

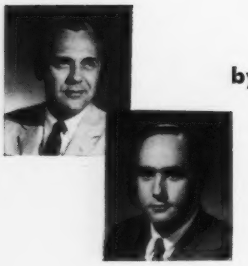
TYPICAL COORDINATION curves for Figure 7 show 0.36 seconds coordination time between main breaker and feeders. **(FIGURE 8)**

COORDINATION between main and feeder breaker is problem of obtaining proper timing. **(FIGURE 7)**

Venture Into Subatomics



NINE-TON magnets with three miles of continuous copper conductor will be used for determining design of future particle accelerator. Windings on solid pole pieces are coated with epoxy-resin during winding.



by **A. N. HAIG**
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Accelerator Section
and
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To gain more basic knowledge in the structure of matter, scientists are now investigating new concepts in accelerator design using higher beam intensities.

GREATER KNOWLEDGE of the structure of matter has come in the last twenty to thirty years with the help of particle accelerators. Cyclotrons, betatrons, synchrotrons, cosmotrons and many other machines have been built in increasingly larger sizes to explore the atom. From these machines have come strange and simple particles which are even a further subdivision of the atom and its nucleus. These particles, with names such as neutrino, antineutrino, muon, pion, and K-meson, have provided a better understanding of the structure of matter. They have also caused physicists to wonder whether these are basic particles or whether further subdivision is possible.

It is in this area that physicists hope to learn more about the subatomic world. Questions concerning the nature and extent of the universe, and the basic particles from which all matter is constructed may be illuminated by this research.

Variety of accelerators now being used

Particle accelerators are designed to accelerate electrons, protons, deuterons, alpha particles, and heavy ions. Energies of accelerators built or under construction in the United States today range from a few million electron volts to 30 billion electron volts. The immediate need is for more accelerators to increase the capacity for experimentation, the extension of energies of electron accelerators, and the improvement of the intensities of proton accelerator beams.

Scientists of a number of universities have formed Midwestern Universities Research Association (MURA) to study these problems.

Increasing proton beam intensities is of particular interest to the MURA group. Proton accelerators have produced strange particles, but slowly and in such minute quantities that it is difficult to study them. Specially designed magnets will assist MURA in proving the design parameters. If the design proves feasible, construction of a full-scale accelerator is planned.

Fixed-field type studied

Most of the recent magnet designs at MURA are of the "fixed-field alternating gradient" type (FFAG). This type of accelerator, which has been called the most exciting recent development in the United States, was conceived by Keith R. Symon of MURA in 1954. One of the differences between the FFAG accelerator and a conventional accelerator is that the magnetic guide field is steady rather than pulsed. This results in the important advantage that a constant field can be operated continuously rather than in cycles or pulses. Continuous operation allows groups of particles of different energies to be accelerated simultaneously so that a very intense beam is built up.

Groups of particles may be injected at short intervals, accelerated to intermediate energies, and these groups

stacked for a fraction of a second. Then the groups may be accelerated to the maximum energy of the machine while other particles are injected. This method gives a much more intense beam of particles, since the limitation on current is generally the acceptance of the machine at low energy. The beam may also be stacked at high energy until it reaches a desired intensity. At that point the beam is ready for experimental use; or it might be injected into a storage ring which would not accelerate the particles but maintain them at maximum energy until another equally intense beam was built up in the accelerator. At this point the two beams could be brought to interact, causing a number of high energy collisions.

Other advantages of a fixed-field accelerator are:

1. Remanence and saturation difficulties with the iron are reduced.

2. Eddy-current distortions of the field disappear.

3. Laminated magnet construction is not required.

4. A metallic vacuum chamber can be employed without distortion of the field.

5. Frequency modulation program for the *R-F* field is more flexible.

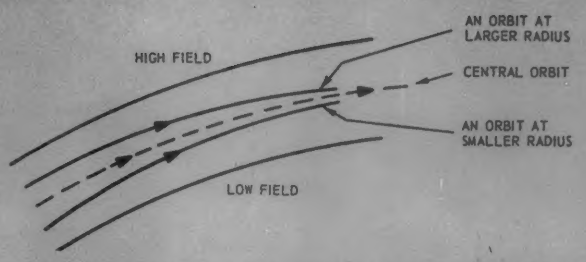
6. Complex switching gear and high voltages associated with pulsed operation are avoided.

Two focusing systems possible

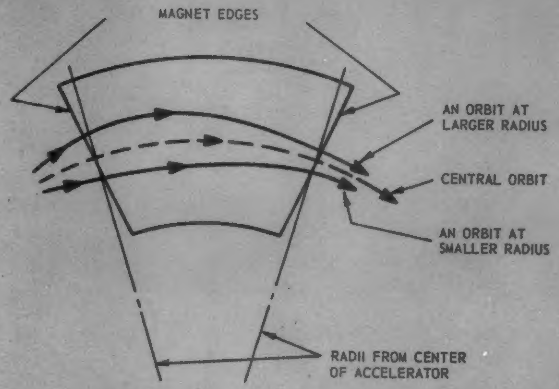
Alternating gradient refers to the type of focusing which the accelerator employs to keep the beam close to the central orbit. Some types of focusing rely on increasing strength of the magnetic guiding field (gradient focusing), or on the increasing length of the magnetic field (edge focusing). In gradient focusing the field varies with the radius. A particle traveling at a larger radius is moving in a stronger field and is bent back toward the central orbit. A particle traveling at a smaller radius and in a weaker field is bent less sharply but also toward this central orbit. Edge focusing also bends a particle traveling at a larger radius toward the central orbit, but because it moves through a greater length of field rather than a stronger field. A particle traveling at a smaller radius goes through a shorter length of field and is less sharply bent, so that it, too, moves back toward the central orbit. Figures 1 and 2 show examples of gradient focusing and edge focusing.

Since particles can drift up and down, they must also be focused vertically. In both gradient and edge focusing, vertical focusing decreases as radial focusing increases. A compromise must be made to ensure that there is focusing in both directions.

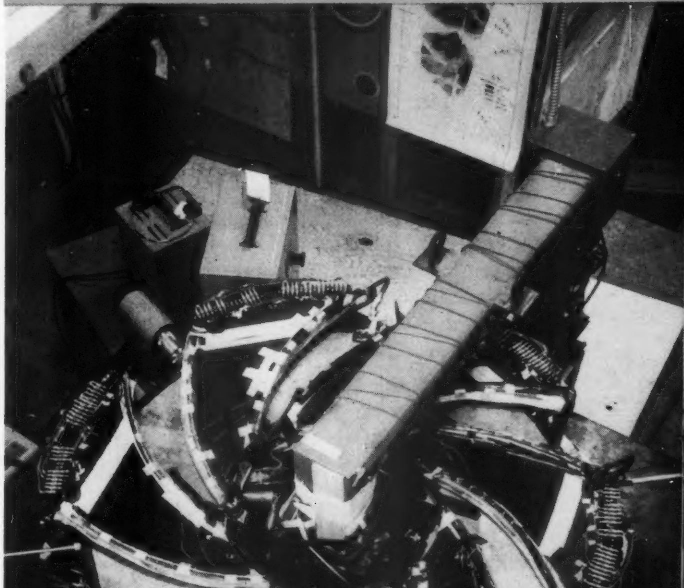
Alternating gradient focusing can be accomplished in several ways. In the conventional alternating gradient accelerator, magnets around the circumference are arranged so that their fields are alternately bowed outward and inward, as shown in Figure 3. The sectors bowed outward provide strong vertical focusing but do not focus radially. On the other hand, the sectors bowed inward provide strong radial focusing but tend to spread the particles vertically, that is, defocus them. The combination



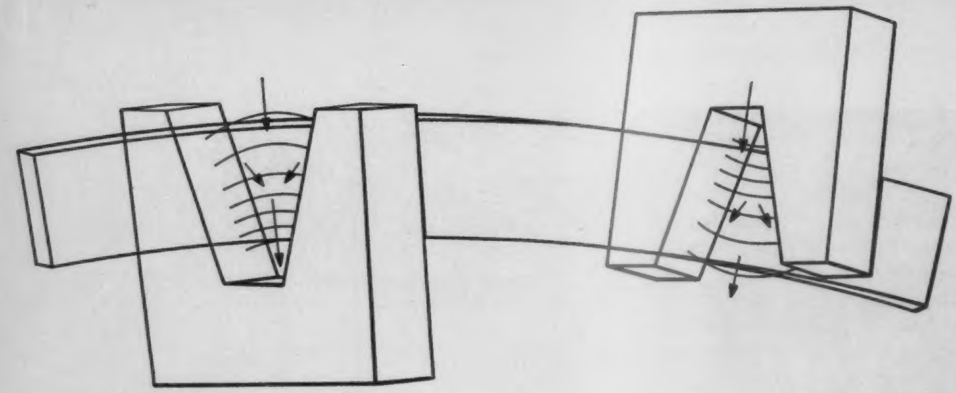
GRADIENT FOCUSING is one method of causing particles of the larger and smaller radii to move toward the central orbit. **(FIGURE 1)**



EDGE FOCUSING depends on greater length of field rather than a difference in field strength to move particles toward central orbit. **(FIGURE 2)**



WORKING MODEL of fixed-field alternating gradient colliding beam accelerator is prototype of machine planned for future experiments.



CONVENTIONAL alternating gradient focusing is provided by arranging magnets so that their fields are alternately bowed out and in. Arrows show force on particles and their lengths show relative magnitude. (FIGURE 3)

of these two types of magnets placed alternately around the accelerator results in a very tightly restricted beam, since the defocusing influences of one are overbalanced by the focusing influences of the other.

Fields are reversed

In contrast to the arrangement just described is the method pioneered by MURA. Instead of causing the gradient of the magnet fields to reverse by changing the direction in which the magnets are bowed, the gradient is caused to reverse by changing the direction of the field. This change in direction is accomplished simply by reversing the current in the magnet coils. Thus alternate magnets around the ring have reversed gradients and the same focusing is obtained as in the conventional alternating gradient machine.

The advantage of this type of arrangement over the conventional machine is very important. A ring of these reverse field magnets has a generally low field around the inner edge and a high field around the outer edge. The magnets can therefore be operated continuously with direct current, and orbits of high energy along with orbits of low energy can be maintained in the accelerator at the same time.

A conventional alternating gradient machine cannot guide particles with a large difference in energy. Consequently, the magnetic field must increase in strength as the energy of the particle increases, thus requiring a pulsed operation. An FFAG accelerator, however, operates continuously, not in pulses, and can therefore build much greater beam intensities.

A great number of variations of the FFAG accelerator were considered. Among these designs were combinations of alternating gradients, magnet edge focusing, ridged magnets, and special variations of magnetic fields. Perhaps one of the most interesting and most challenging is the colliding beam type of accelerator, a working model of which has been built.

The colliding beam accelerator is an FFAG with two beams rather than one. These beams travel in opposite directions in the accelerator and are made to collide when they reach the desired energy. The colliding beam concept is possible because a magnetic field acts oppositely on particles that enter the field from different directions. A particle entering the field from one direction may be bent toward the center of the circle, whereas a particle entering from the opposite direction will be bent away from the center. As a result, the particles going in opposite directions weave in and out as they go around the circle and yet remain in orbit. Although electrons have been accelerated in both directions simultaneously, the maximum energy has not yet been achieved.

Possibilities are startling

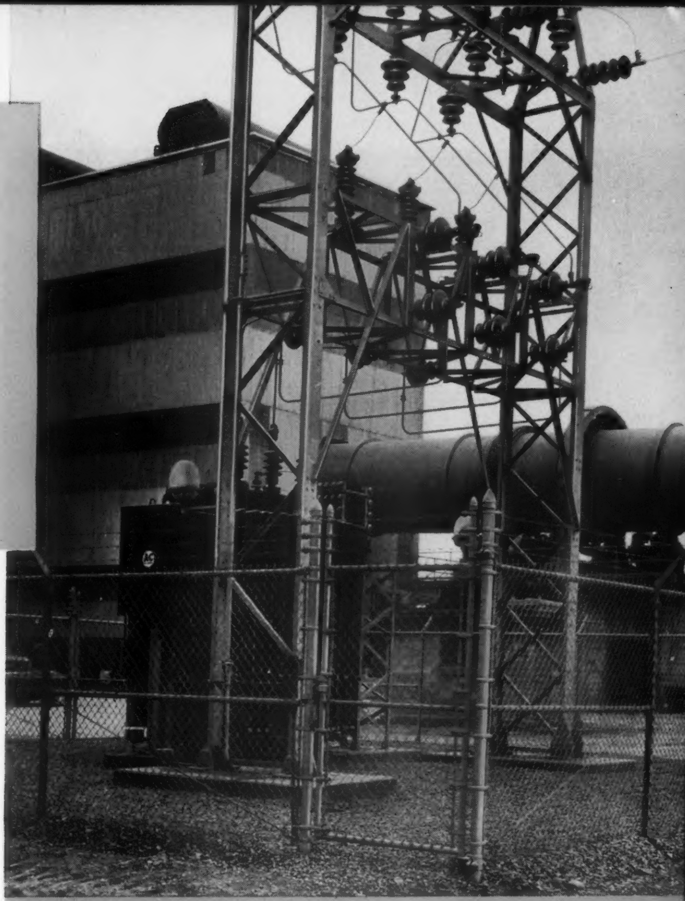
A full-scale machine producing two beams of 15 billion electron volts can produce collisions equal in energy to that of a conventional machine with a single beam of 540 billion electron volts. This results from the elimination of the energy lost by a single beam striking a stationary target and from a geometric gain on the effect of two beams colliding head on.

The most powerful accelerator in existence today is the 25-30 billion volt unit at CERN, the European center for nuclear research in Geneva, Switzerland. The United States has a comparable unit under construction at the Brookhaven National Laboratory.

MURA's present plans are to build an FFAG accelerator in the 10-15 billion volt class to meet the need for a high intensity proton accelerator. Effort and research in the colliding beam accelerator will be continued until the feasibility of this type of unit can be proved.

EARLY MODEL of spiral sector fixed-field alternating gradient accelerator is prototype of larger unit which MURA proposes to build.

ANTICIPATING 1970's INDUSTRIAL LOADS



SYMBOL OF MODERN INDUSTRIAL POWER, 5000-kva primary substation powers advanced cement manufacturing process. *Grate-Kiln* system used for processing wide variety of raw materials and ores is employed in this Midwest plant.

by **W. E. KORSAN**
Assistant Manager
Industrial Systems Dept.
Allis-Chalmers Mfg. Co.

Large blocks of precisely controlled energy needed to exploit our resources will be a major factor in industrial load growth.

WHILE POPULATION GROWTH and higher standards of living are causing broad industrial expansion, that portion of load growth which requires careful study is the increased power required to convert tomorrow's basic raw materials into finished products.

New techniques, new processes, operations at remote locations, greater conversion power for lower grade raw materials, and higher product quality all mean increased power requirements. Higher material and process speeds with closer control are also major factors affecting future industrial power requirements. Process and load requirements in the basic industries are indicative of our future needs.

Mining and quarrying loads have grown

New processes, such as the *Grate-Kiln* system, are coming into use for lower grade raw materials. With readily available iron ore decreasing in content from 45 or 60 percent iron to 20 or 40 percent, increased tonnages must be processed. In addition, the ore must be finely divided to secure the iron content and then reconstituted into larger particles for shipment and for charging of refining furnaces.

Substantial quantities of water for washing, and fuel for subsequent drying will be added requirements for such plants. Greater crushing, grinding, and conveying of ore are also expected to increase connected horsepower. For an output of 4000 tons per day an increase of from approximately 2500 hp to 15,000 hp is expected. A typical plant may have three to four times this output.

The input and output chemical analysis, feed rate, particle size, and temperature will all be quite critical and interrelated with machinery speeds at several stages during the process. Precise measurements and control are a must.

Similar problems will exist with materials such as sulphur, coal, limestone, and petroleum. These operations will likely be carried on at locations remote from normal utility services.

Looking ahead in metal processing

New melting methods will be necessary for many materials. Steel and iron furnaces may use fuel for direct exposure to combustion conditions wherein air quantities and pressures will require variable-speed prime movers of from 25,000 to 30,000 hp. Electric furnace power requirements will change from 25,000 kva for large units to 40,000 or 50,000 kva for future units requiring induction stirring. Such units produce violent load disturbances which must be dampened through use of synchronous con-

densers, buffer reactors, regulators and specially designed transformers to limit flicker in nearby areas. Similar electric furnaces for vacuum melting will use dc through semi-conductor rectifiers rated as high as 50,000 amperes.

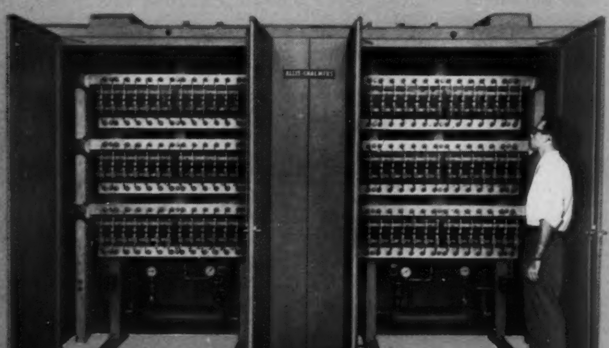
While submerged arc furnaces for such nonferrous materials as refractories and phosphorous will increase from 40,000 kva to 50,000 kva or more, they will not produce severe electrical disturbances to the system.

Metal rolling results in large, hard-to-handle loads. Large reversing mills now use motors of up to 16,000 hp with peak loads of up to 44,000 hp at 16 peaks per minute. Ratings of 20,000 hp and peak loads of 55,000 hp are foreseen. A continuous rolling mill may increase installed motor horsepower from present 40,000 hp synchronous or 50,000 hp direct current to ratings where total peak load per mill may become 150,000 to 200,000 kva over a 45-second period, decreasing to occasional valleys of 10,000 to 15,000 kva. Dc power source is likely to change from motor-generator sets to mercury-arc rectifiers or possibly to controlled diode semi-conductor rectifiers.

Cold rolling speeds of 7000 fpm and hot rolling speeds of 3000 fpm will not be rare. Such mills will normally be equipped with fully automatic computer and programming sequence controls for reduction, uniform thickness, surface, temperature, marking, and data logging, since the human operator cannot consistently react with the required speed or accuracy.

New methods of producing super-fine surface, ultra-thin materials for standard and special alloys at high speeds are now beginning initial installation and trials. Drastic changes in quality and power consumption are expected.

The use of rare and inert gases as well as oxygen to meet special requirements in melting and rolling is already skyrocketing. Not only small vessels and enclosures but entire large rooms will have atmospheres in which man cannot breathe unaided. Our space program plants for extraction of these gases from the air are only the beginning. In such plants, compressor loads of 10,000 to 35,000 hp will be normal. Practically all industrial areas will have such plants.



EXPANSION IN THE 1970's will bring an increased need for power conversion equipment such as this 10,000-amp water-cooled silicon rectifier unit.

In cement, lime and other raw material processing, the trend is to larger and larger units. Today, grinding mills have 3000-hp driving motors and these motors are started across the line. By the 1970's grinding mill motors are expected to be 4000 to 5000 hp.

Cement and other process kilns are also getting longer and bigger in diameter. One kiln being built, measuring 18 feet inside diameter and 600 feet long, will have 500 hp in driving motors to produce almost 9000 barrels of cement per day.

These are desirable loads, since they normally operate 5 to 7 days a week, 24 hours a day for months on end, with only slight load variations.

Electrochemical industry production up

A notable example of large power requirements is the aluminum industry, which requires approximately 8 kwhr per pound of primary aluminum produced. In a recent installation, a mercury-arc rectifier power supply will produce a total of approximately 200,000 kw for an entire plant when in full production.

Future power conversion equipment for such a plant may well be controlled silicon diode or semi-conductor rectifiers.

The chlor-alkali and electrolytic metal-refining industries use similar equipment and produce the same type of loads, generally ranging from 5000 kva to 30,000 kva.

Test facilities are already large

Test facilities are interesting, intriguing, and yet most difficult to design, operate, and supply power-driven equipment. The Air Force Development Center at Tullahoma, Tenn., has a total of five facilities. The largest includes a wind tunnel and compressors driven by two 83,000-hp motors which are started by two 25,000-hp wound-rotor motors. With all five facilities operating simultaneously, the total load would consist of approximately 750,000 hp. Test durations are usually one day or less at infrequent intervals, making power supply a real problem.

Rocket testing is extremely interesting today. Testing of such components as pumps alone, can require the use of up to 30,000 hp over a maximum period of two hours. Because of the associated equipment and noise levels, test sites are generally located in fairly remote areas.

Missile designs for space and military use will be tested using an arc chamber. The overall specifications may include such conditions as:

1. Air speed of 30,000 mph.
2. Temperature 40,000 F.
3. Pressure 30,000 psi.
4. Time 1/10 of a second.

It is expected that these arc chambers will have power supplies up to 40,000 kw.

The scientific world is delving deep into matters concerning space. One current project is a new particle accelerator for the Argonne National Laboratories near Chicago. From the utility point of view, this may be

particularly interesting because it will actually develop a peak load of 117,000 kw dc, with these peaks coming at the rate of 15 per minute. The power supply will be mercury-arc rectifiers taking ac power from a flywheel-driven motor-generator set.

By using flywheels and other engineering innovations, the 117,000-kw peaks will be reduced to an average of 15,000 kw plus or minus 5000 kw at the 15 peak per minute rate. This load will remain relatively steady for several weeks at a time.

Another interesting test facility is currently being designed for testing tires. Equipment will include a 10,000-hp variable-speed driving motor. The motor will be subjected to loads running for periods of from two minutes to four hours, with the horsepower varying during the period of a test.

Larger short-circuit facilities for testing such equipment as fuses, disconnect switches, and reclosers are being planned. Currently, a typical transformer reflects a 250,000 kva surge on its power supply. We expect to see these surges increased to nearly 500,000 kva at intervals of 15 minutes.

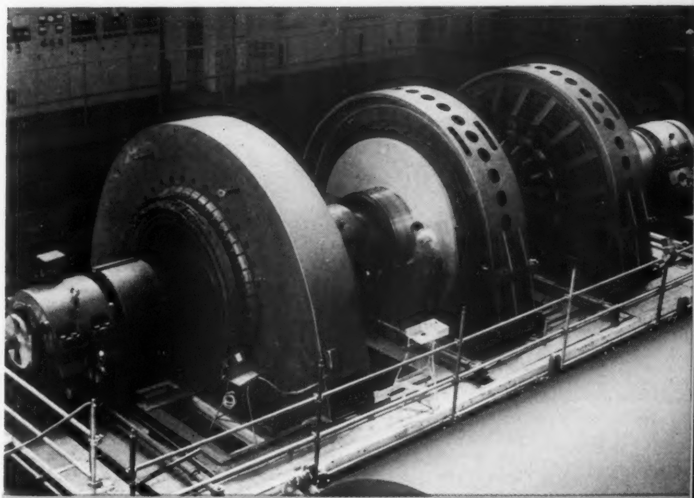
More electricity per unit of manufacture

In general, the electrical industry is going to be continuously subjected to increasing loads, a significant amount being highly variable peak loads. This use of electric power will mean larger blocks of power for locations close to metropolitan areas having strong power systems and also to fairly remote plants. Transmission of power will still involve serious voltage and frequency variations.

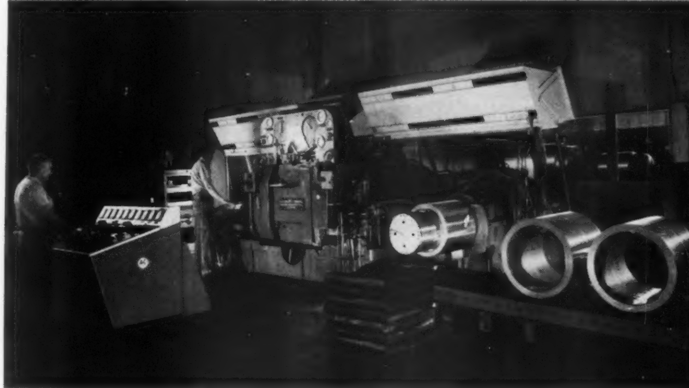
With engineered systems and automatic controls, the cost per plant will rise drastically and can only be offset by increases in production and improvements in maintained high quality. Because of the delicate controls used in these systems, power supplies must have precisely regulated frequency and voltage. Static power converters for variable-frequency drives, and for control circuits using frequencies of 360 to 420 cycles, will become predominant by the 1970's. Continuity of service will be a must, since the high cost of the original plant and its capacity will mean an extremely high charge per hour of unscheduled down time.

As demands for quality become more and more rigorous on the customer's part, and the process becomes more and more a "through-put" instead of a "batch," such loads will mean the constant merging of simultaneous peaks. High, relatively flat base loads and fewer high momentary peaks will result.

Projecting today's rapidly expanding industrial loads into the 1970's is a key to the power expansion that will be needed to meet these loads. Plans for industrial loads should include new techniques and processes, higher speeds, greater quality control and advanced test facilities. Basic resources will require more power for processing and sources will be more remote. When these factors are considered, industrial loads will grow far faster than might be expected.



ON TEST is partially assembled 16,240-kw, five-machine motor-generator set for C Stellarator. Each generator is capable of handling pulse currents up to 22,300 amperes at 860 volts. Flywheels absorb load fluctuations.



MAIN STAND AND REEL drives for this Sendzimir cold strip mill consist of two 200-hp twin drives and a 500-hp, 600-volt dc motor. Mill produces 25-inch-wide brass and copper strips at speeds up to 1200 fpm.

FIVE ROTARY KILNS in San Adreas, California cement plant show expansion with larger units. While such plants may be located away from major industrial areas, they represent good steady loads to the power companies.

CLOSER OVERLOAD PROTECTION FOR POLYPHASE MOTORS

ADJUSTABLE, temperature-compensated thermal overload relays can provide closer protection to polyphase motors. The authors examine redesigned relays installed in a high voltage motor controller.

by **T. F. BELLINGER and R. A. GERG**
Control Department, Allis-Chalmers Mfg. Co.

Overload protection for large ac motors operating under adverse conditions is getting more attention.

POLYPHASE MOTORS are normally rated in degrees of allowable temperature rise above an established maximum ambient temperature. The permissible temperature rise is a function of the class of insulation and the motor cooling employed. For most types of motors the maximum permissible insulation temperature, when measured externally by thermometer, is 90 C for Class A insulation, 110 C for Class B insulation, and 150 C for Class H insulation. Full Class H insulated machines are seldom produced in larger sizes because of the mechanical problems encountered when operating them at Class H temperatures.

Machine manufacturers have adaptations of Class H insulation which permit temperatures in excess of the Class B insulation but below the extremely high temperatures of Class H insulation where the mechanical design considerations become complex.

Service factor allows for some overload

A typical temperature rating for an open-type fan-cooled polyphase motor is designated as 40 C/40 C, which means the motor has a nominal rating of 40 C rise above a 40 C maximum operating ambient. This rating establishes a total maximum temperature of 80 C, which is 10 C short of the 90 C maximum temperature permitted for Class A insulation. To use the additional 10 C temperature capacity, the motor is given a continuous service factor rating of 1.15. The motor can therefore be operated continuously at 1.15 times greater load than its nominal nameplate rating. A motor having Class A insulation might also be rated 50 C/40 C, indicating that the motor has an allowable 50 C rise over a maximum ambient of 40 C. Here the maximum permissible insulation temperature is again 90 C, corresponding to the limit for that class of insulation. A motor rated in this manner would have a service factor of 1.0 and can be operated to a maximum of nameplate rating with no continuous overload factor.

Motors having Class B insulation may have temperature ratings of 60 C/40 C or 70 C/40 C, with the first rating having a service factor, while the second having a service factor of unity. Motors may have various continuous service factors of 1.0 and above, but usually a service factor of 1.25 is maximum. However, intermittent service factor ratings for motors go far beyond this value, depending upon the particular application. Figure 1 indicates the rate of deterioration of Class A insulation with elevated temperature.

Maximum use is obtained when motors are operated as close as practical to the maximum prescribed temperature corresponding to the insulation class. As this temperature limit is approached, the importance of adequate overtemperature protection becomes more critical. The purpose of overtemperature or overload protection is to allow the motor to be operated near its maximum temperature limit and to disconnect the motor from the line when the temperature limit has been exceeded.

Devices providing such protection must be either directly operated from the motor winding heat or responsive to stator current, which is a function of the motor heating. Devices which measure directly the insulation temperatures must be located within the winding. Although outwardly this system appears to be the most logical, the detecting equipment is subject to numerous application limitations. Current-operated overload devices are normally located within motor starters mounted remotely from the motors.

Current-operated devices vary greatly in principle, but all have inverse operating time characteristics similar to the characteristics shown in Figure 2. They may be either

magnetically or thermally operated. The magnetic type usually consists of a current-operated solenoid which actuates a dashpot or similar escapement contact mechanism. Thermally operated overload relays consist of elements which are heated by the flow of motor stator currents. The temperature produced may soften low melting alloy elements to release an escapement mechanism or cause bimetallic elements to deform and thereby initiate tripping operations. Bimetals may be either directly heated by current passing through them or they may be indirectly heated by heating elements which carry the motor currents. All types of overtemperature or overload devices, normally referred to as overload relays, are placed directly in series with the motor phases when practical or may be connected to the secondaries of current transformers where voltage and current limitations dictate.

Close coordination important

How close a motor can be operated to its maximum permissible insulation temperature and the degree of protection provided depend considerably upon the type and the quality of the protective device used. The coordination of relay to motor characteristics is shown in Figure 3.

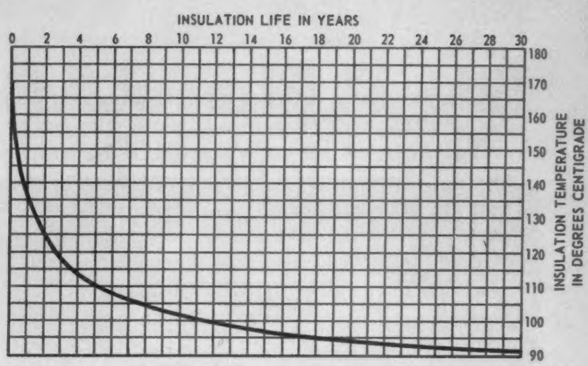
Thermal relays are either compensated or uncompensated. An uncompensated relay is affected by the ambient temperature surrounding it. If the temperature surrounding the heater coil and the relay is increased, the relay will operate with less motor amperes passing through its heater coil than it would if the ambient is at a lower value. On the other hand, in a compensated relay the same amount of motor amperes are required for tripping regardless of the ambient surrounding the relay.

The degree of motor protection or the relay limitations when using a standard line of heater coils can be found by analyzing Table I. For example, under the 1.00-minimum full-load motor current, heater trip current is given at 1.25 amperes. This means that if the heater coil is applied to a motor with full-load current of 1.00 ampere, the relay would not trip until current had risen to 125 percent of this value. This seems inconsistent, since a motor can stand only an overload of 115 percent before it reaches its maximum rated operating temperature. On the other hand, with the maximum value of 1.13, 1.25 amperes is only 110 percent of this value. Using this heater on a motor with a full-load current of 1.13 would mean that the motor could only be overloaded to 10 percent above its value before the relay would trip. The motor would thus be prevented from reaching its maximum capable output.

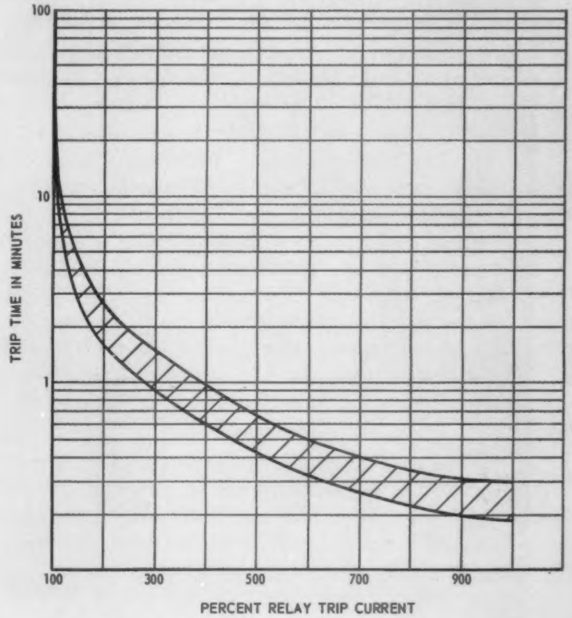
It is impractical to supply a heater coil for each line of different values of full-load motor current. The figures shown were taken from a table which has become an

TABLE I

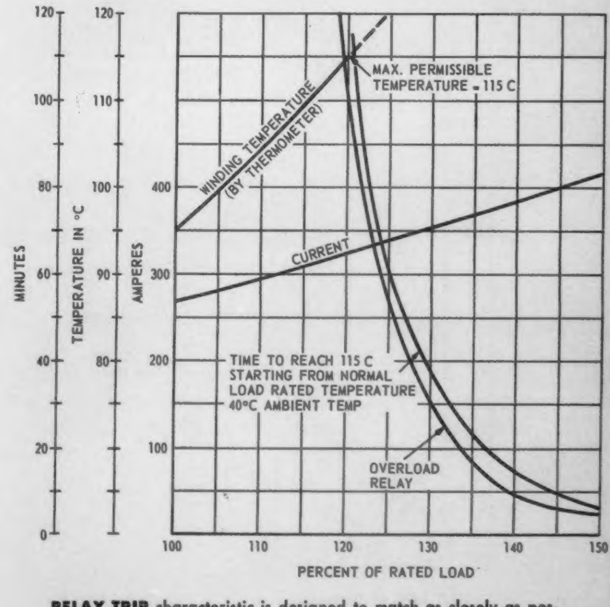
FULL-LOAD MOTOR CURRENT		
Minimum	**Maximum**	**Trip Amperes**
.74	.85	.93
.86	.99	1.08
1.00	1.13	1.25



CLOSER PROTECTION is key to longer insulation life of polyphase motors. Allowing a motor to run only slightly overloaded will greatly diminish its years of service. **(FIGURE 1)**



TIME-CURRENT characteristics are given for compensated overload relay. Temperature compensation maintains trip current characteristic regardless of relay ambient temperature. **(FIG. 2)**



RELAY TRIP characteristic is designed to match as closely as possible temperature-time curve of motor windings. Coordination is obtained by heater selection and relay adjustment. **(FIGURE 3)**

industry standard. If closer overload protection is desired, an adjustable type of thermal overload relay can be used. An adjustable relay is one which will change a trip current from 1.25 amperes to a lesser or greater value. All types of overload relays are not adjustable. In general, adjustable relays are only available in the higher price category. For example, the melting alloy type relays used in smaller controls are usually of the nonadjustable type, whereas certain bimetallic types are adjustable over a range of plus or minus 20 percent.

Table only a guide

Generally, a heater coil should not be selected from relay tables for motors without a service factor. However, if a heater coil must be selected for a motor without a service factor, the full-load current of the motor should be matched as closely as possible to the trip amperes of the heater table. When applying a motor with full-load current of 1.15 amperes, table trip current will not match the motor full-load current. In the trip amperes column, 1.15 amperes is half way between the 1.08-ampere trip value shown for one heater and the 1.25-ampere trip current value shown for the other. With a nonadjustable type of overload relay, the relay would trip the motor out prematurely by limiting its output to 1.08 amperes or would cause possible burning out by not tripping until the motor reaches 1.25 amperes. However, if an adjustable relay is used, the 1.08 and the 1.25-ampere heaters can be rerated to the 1.15-ampere trip value of the motor.

When motors are driving vital or specially designed machines, or when higher rated motors are needed, the choice of motor overload protection becomes exceptionally important. One approach to these protection problems is the recently redesigned bimetallic overload relay shown in Figure 4. These adjustable and temperature-compensated relays were designed for application in dusty locations or in atmospheres having corrosive fumes, such as cement plants, foundries, crushing plants, refineries, pumping stations, fertilizer plants and chemical plants.

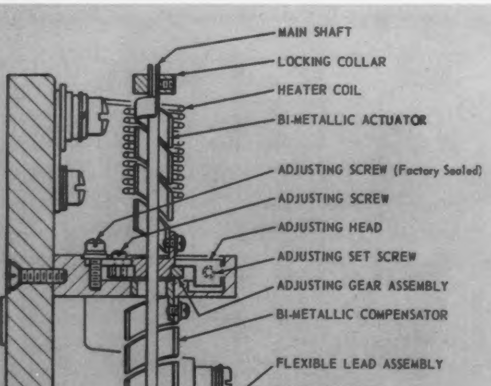
The design improvement was based on a new free-floating single guide bearing. For extremely corrosive atmospheres, the relays can be placed in a vapor-proof enclosure, as shown in Figure 5.

High inertia starting a problem

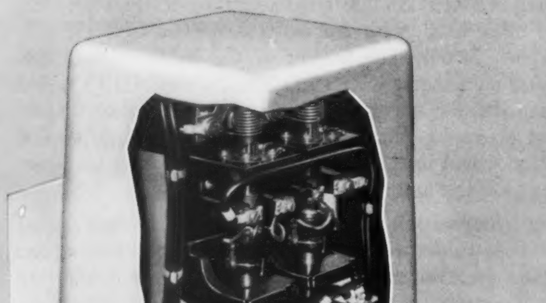
In certain applications where motors are driving high inertia loads having correspondingly long accelerating times, the motor stator and rotor windings will not be completely protected by standard overload relays alone. Modern motors draw from 500 to 1200 percent full-load running current during starting. With normal relay settings the relays would trip during start or in some cases shortly after the motor has reached full speed. If the motor is designed to withstand long accelerating periods, tripping of the relay may become a nuisance to maintenance people or may limit the load that can be started.

For these applications, a precision reactor can be connected in parallel with the relay heater. The taps on the reactor coil are set to make the reactor saturate at about 200 percent relay trip current. At this point the excessive motor current will be bypassed through the reactor. The arrangement allows the motor to start and also protects against overloads under normal running conditions.

In modern control practice, more thought is being placed on motor protection because the false tripping of a motor in important processes can interrupt complete operations. On the other hand, the lack of proper protection can cause motor insulation deterioration and eventual failure. For these reasons selecting a precise relay and adjusting it to trip accurately at maximum motor rating is important in safeguarding costly machines and processes.



ROTATION of bimetallic actuator is caused by heat from heater coil. Bimetallic compensator governs trip point with relation to ambient temperature. (FIGURE 4)



VAPOR-PROOF ENCLOSURE and electrical reset are available for locations in which relays might be exposed to severely corrosive atmospheres. (FIGURE 5)

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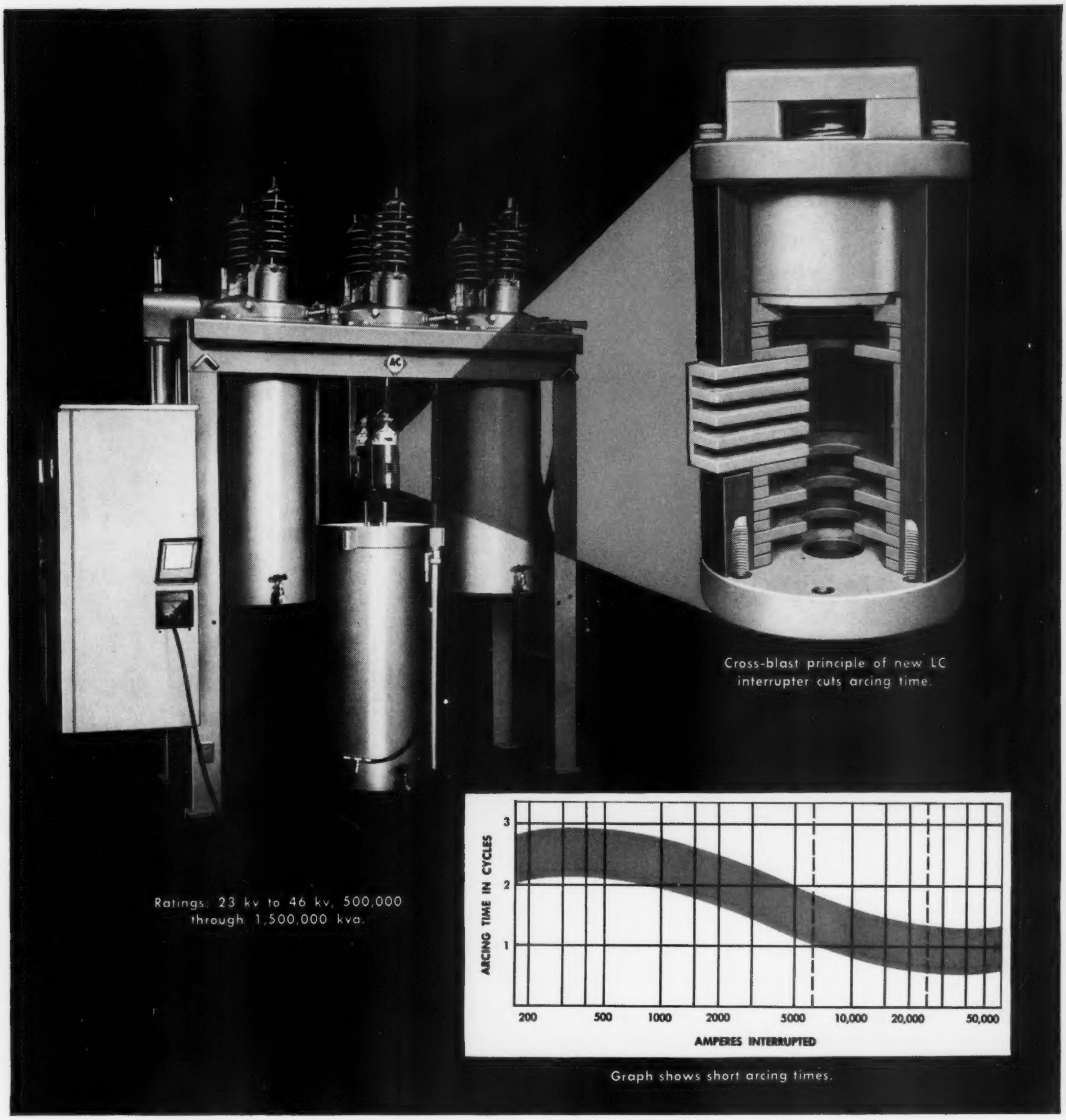

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Ratings: 23 kv to 46 kv, 500,000 through 1,500,000 kva.

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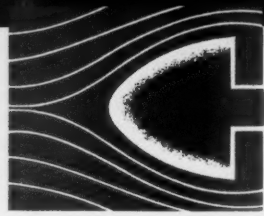
New Technological
Advance in Re-entry Simulation



ROCKET AND SPACE CAPSULE design improvements are envisioned through the establishment of more advanced aerodynamic testing facilities. The prototype facility shown utilizes a crossed-field accelerator to simulate either fast or slow re-entry conditions in continuous tests.

Plasma acceleration is obtained as the result of a magnetic field acting at right angles to an electric current passing through the plasma stream. The direction of the plasma stream is at right angles to both of these effects. Additional acceleration is obtained as the plasma passes through a diverging nozzle to produce the desired hypersonic velocity needed for test model rocket vehicles in simulated operating conditions.

A 60 percent increase in kinetic energy has been obtained in a continuous Mach 3 flow of partially ionized argon in the prototype system. The current through the plasma is maintained in the presence of a 9000 gauss magnetic field which is oriented to increase velocity. Plasma acceleration is achieved by applying a forward arc voltage across the electrodes which is larger than the back emf.

Tests in argon have shown that an applied voltage of approximately four times the back emf is required to maintain stable current at a fixed level as the strength of the magnetic field is increased from 0 to 9000 gauss.

Present development work involves a study of arc stability in the partially ionized hypersonic stream. Important parameters in this study include the local plasma stream velocity and changes in electrical conductivity in the plasma.

Another important study involves high temperature materials. Since heat-transfer rates are high in crucial areas where the material is electrically non-conducting, ceramic materials are presently utilized.

Continued development is being directed toward the improvement of the present prototype system.

by R. C. ALLEN
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